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# A study on the energy performance of hotel buildings in Taiwan

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ABSTRACT

This study presents a discussion on the energy performance of hotel buildings in Taiwan. Energy consumption data, building information, and other operations data were collected from 45 Taiwanese international tourist hotels, 19 standard tourist hotels, 116 hotel enterprises, and 20 bed and breakfast facilities. The energy use intensity (EUI) of the 4 rated hotels is 280.1, 237.7, 186.3, and 143.6 kWh/m$^2$/year. Mean energy consumption per guest room at the 4 rated hotels is 26.7, 25.0, 14.6, and 9.4 MWh/room/year. Electricity predominantly comprises total energy consumption, which accounts for 84% of total energy on average. Pearson correlations between EUI and possible explanatory indicators revealed that certain building conditions, operations, and other factors are significant. Two regression models were established to predict annual energy consumption and EUI, and gross floor area, number of guest rooms, occupancy rate, and building construction year were selected as independent variables. The coefficient of the adjusted $R^2$ is 0.928 and 0.612, which implies reliability. This study provides managerial suggestions according to the results for improving hotel energy performance.

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## 1. Introduction

The tourism industry has been developing rapidly in Taiwan for the past three years. Because of the recent moderation of the political climate between Taiwan and China, mainland tourists have begun visiting Taiwan in large numbers. According to the published data on visitor arrivals, the percentage of inbound tourists rose by 14.3–26.67% in 2009 and 2010, respectively [1]. In addition, because of the economic recovery, the number of domestic tourists rose by 7.67% and 14.86% in 2009 and 2010, respectively [2]. Prosperous tourism contributes to significant growth of the hotel industry in Taiwan. As of 2011, the total number of the highest rated international tourist hotels in Taiwan is 70 (with 20,497 rooms), that of the second highest rated standard tourist hotels is 37 (5072 rooms), that of the third highest rated hotel enterprises is 3169 (124,100 rooms), and that of basic rated bed and breakfast facilities is 5582 (15,415 rooms) [3]. For example, of the highest and second highest rated hotels, the number of rooms rose by 11.7% and 38% this year, respectively. In the coming five years, at least 6645 rooms of international tourist hotels and 2476 rooms of standard tourist hotels will be built, with some of them already in construction. The number of employees of all the hotels is 72,252, the total revenue is US$3.3 billion; the total number of employees and revenue comprise 24.5% and 22.2% of the total tourism industry in 2011, respectively.

The international hotel sector is one of the largest drivers of global employment. The accommodation sector was estimated to account for 21% of carbon dioxide emissions from tourism [4]. Furthermore, the hotel facilities only minor to food services, sales, health care and offices, rank the 5th position in terms of energy consumption in the commercial/service building sector [5]. Reviews of a number of studies on hotel energy consumption are listed in Table 1. Overall, the annual average energy consumption per floor area for hotels is related to climate. Hotels located in extremely cold [6] and hot areas [7–11] consume substantially more energy than those in relatively mild climates [12–17]. Most studies detail all energy sources, including electricity, gas, LPG, diesel oil, and coal. However, only three studies focused on electricity consumption [9,14,18]. Yet, electricity consumption accounts for 75% [12], 73% [8], 82% [10], 66–91% [14], and 45–62% [16] of total energy. Typically, nearly half the electrical energy generated is used for space conditioning purposes [19]. Most of the studies gathered statistics on energy consumption through investigations [6–18,20], whereas a few studies discussed EUI by simulations [21–23]. The maximum sample number of the studies is 184 hotels [20], whereas the minimum number of samples is 1 [15]. Regarding the generalizing factors that influence the EUI of hotels, various methods and combinations were used in the literature. Some of the findings reveal that high or low ratings (star level) influence the EUI because of the complexity of services provided [8,10,14,16,23]. Some considered hotel size to influence energy consumption [10,11]. Others deemed different types or characteristics to influence EUI [12,14,16,20,23]. Whereas certain studies focused on equipment owned by the hotels or the living conditions of the hotels [8,13,17,18], others

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**Table 1**
Average energy consumption for hotel buildings worldwide, kWh/m$^2$/year.

| Country or region (data for the year) | Energy use intensity (EUI)(kWh/m$^2$/year) | Source | Additional remarks |
|---|---|---|---|
| Canada (1994) | 689 | [6] | 19 hotels (located within Ottawa) |
| Hellenic (1994) | 273 | [13] | 158 hotels with 140 in Athens |
| Hong Kong (1995) | 563 (297–936) | [8] | 16 hotels (guest rooms between 216 and 862): 5* (9), 4* (4), 3* (3) |
| Hong Kong (1997) | 542 (147–981, std. = 203) | [7] | 36 5* hotels |
| Hong Kong (2000) | 342 | [9] | Electricity use only 17 hotels |
| New Zealand (2000) | 159 (hotel)<br>83 (bed and breakfast)<br>69 (motel)<br>171 (backpacker) | [12] | 107 hotels: hotel (30), bed and breakfast (22), motel (20), backpacker (35) |
| Vietnam (2000) | 4* = 141 (80–237)<br>3* = 143 (41–426)<br>2* = 101 (26–271)<br>Resort = 78 (9–165) | [14] | Electricity use only<br>50 hotels: 4* (9), 3* (25), 2* (12), resort (4) |
| Tunisian (2002) | 171 | [15] | Energy audit<br>1 hotel |
| Spain (2003) | 4* = 179 (std. = 28)<br>3* = 129 (std. = 24) | [16] | In the Balearic islands<br>31 hotels: 4* (11), 3* (20) |
| Mediterranean countries (2003) | 174–287 | [17] | 4 hotels |
| Europe (2004) | Hilton = 364 (129–859, std. = 149)<br>Scandic = 285 (124–568, std. = 94) | [20] | 73 hotels (Hilton)<br>111 hotels (Scandic) |
| Turkey Antalya (2005) | 389 (129–646) | [18] | Electricity use only<br>32 hotels |
| Singapore (2008) | 427 (265–592, std. = 96) | [10,11] | 29 hotels (guest rooms between 32 and 1200): 5* (11), 4* (13), 3* (5) |
| UK (2009) | 368 | [21] | Energy use simulation<br>2 hotels (representative of 67% of hotels in the UK.) |
| Taiwan (2010) | 295 (international tourist hotel)<br>238 (standard tourist hotel)<br>186 (hotel enterprise)<br>144 (bed and breakfast) | This study | 200 hotels: international tourist hotel (45), standard tourist hotel (19), hotel enterprise (116), bed and breakfast (20) |

considered EUI in relation to the operations data, such as occupancy rate, guestroom, guest night, and revenue [7,8,11,12,14,20,24].

## 2. Background

Taiwan, an island with an area of 35,759 km$^2$, is located on the Northern Hemisphere, and the Tropic of Cancer passes through central and southern Taiwan. Taiwan is located in a subtropical region with long hot and rainy summers. Summer lasts from early May to October, and northern Taiwan has a shorter summer than the south. The main sources of energy consumed by Taiwan hotels are electricity (for space cooling and dehumidification, lighting, appliances, drinking water, boiling, and pumping water), gas (for cooking and heating water), and diesel oil (diesel generator and as boiler fuel). Electricity predominantly comprises total hotel energy consumption. Table 2 shows the statistical summary of energy usage in Taiwan. Electricity consumption accounts for 84% of total energy on average. The requirement for winter heating in Taiwan can is almost negligible. Space heating is provided only in high-quality hotels when the outdoor temperature is lower than 10 °C, which is a rare occurrence in Taiwan. Therefore, most of the hotel samples do not require space heating during winter, except those located at higher altitudes. This is the reason the minimum electrical/total energy percentage is low, but the average is close to the median, and the standard deviation is also low. Fig. 1 shows the breakdown of typical energy consumption, outside temperature, and occupancy. Energy consumption appears more relative to temperature, especially in the summer. The Pearson correlation coefficient of energy consumption and temperature is 0.88. Overall, energy consumption from May to October is higher than in the remaining six months by 32.5%.

## 3. Hotel characteristics and basic statistical data

The sampled hotels are distributed well around the island. Selected samples comprised 302 hotels, of which 200 were considered valid samples. Sampled hotels can be categorized according to four levels: the highest level is international tourist hotels (45 samples), the second level is standard tourist hotels (19 samples), the third level is hotel enterprises (116 samples), and the basic level is bed and breakfast facilities (20 samples). Each level possesses different characteristics; for instance, international tourist hotels vary from a boutique hotel with 76 guest rooms, compared to a large establishment maintaining 856 rooms. All samples are shown in Table 3. The total sample number of international tourist hotel rooms is 14,607, which is 73% of the total number of available rooms in all registered international tourist hotels [3]. The total sample number of rooms of standard tourist hotels is 3930, which is 79% of all registered hotels. The sample numbers of rooms of hotel enterprises and bed and breakfast facilities are 4971 and 100, respectively, which accounts for only 4% and 1% of all registered hotels. The hotel gross floor area (GFA) data and construction year data were collected from building usage licenses granted by the local government. Business operations data were mainly available from the interior statistical details provided by the government organization Tourism Bureau of Taiwan. The electricity

**Table 2**
Percentage of electrical and total energy ratio of hotels in Taiwan.

| Electrical/total (%) | Maximum | Minimum | Average | Median | Standard deviation |
|---|---|---|---|---|---|
| International tourist hotels | 98 | 48 | 83 | 84 | 11 |
| Standard tourist hotels | 96 | 22 | 86 | 91 | 17 |
| Hotel enterprises | 99 | 56 | 86 | 89 | 9 |
| Bed and breakfast facilities | 95 | 58 | 82 | 84 | 10 |

consumption data were provided by the electric power plant Taiwan Power Company, and gas and diesel consumption and the other data were obtained from in-depth interviews with hotel management.

GFA shows an obvious ranking in the four types of hotels: the average hotel GFA of the first ranking is 95 times that of the final ranking. Per guest room is 95 $m^2$ of the GFA in international tourist hotels, 102 $m^2$ in standard tourist hotels, 78 $m^2$ in hotel enterprises, and 65 $m^2$ in bed and breakfast facilities. The GFA of the highest and second highest rated hotel types are substantially higher than those of the last two rated. This is because they are luxury hotels, in which more space is used for leisure activities. Furthermore, all hotels provide dining facilities to enhance their total revenue; the total revenue is mainly contributed by food and beverage (F&B) and rooms. In international tourist hotels, for example, the area for dining facilities includes mainly the restaurant, kitchen, and café, varying from 1.1% to 9.6% of the GFA. On average, 5.9% of the GFA is used for this purpose. The average F&B revenue is 0.3–2.6 times the room revenue in the four rated hotels. F&B revenue is often high on particular festival days or rush seasons, especially during Chinese New Year (most in later January). Therefore, the energy consumption and revenue of F&B in this period are substantially greater than in any other period. This leads to high energy consumption in the beginning of the year, which is the reason both the outdoor temperature and occupancy are low, but energy consumption is high in January (Fig. 1). In addition, 11 international tourist hotels are located in populated downtown districts, which comprises an average 12.3% of the GFA as the shopping center or/and department store. This propels the total revenue to be substantially higher than the room revenue in certain samples.

For the hotel scale, the highest rated hotels often consume substantially more energy than the others. The average cost of energy consumption for every international tourist hotel is US$1,092,168, which is 4.9% of total revenue. The former data in the other ratings are US$652,050, which is 5.7% in standard tourist hotels, US$82,908 in cost, which is 7.7% in hotel enterprises, and $6737 for bed and breakfast facilities, which is 3.0% of total revenue. Both the occupancy rate and average room rate indicate that higher rated hotels signifies higher data figures. In other words, international tourist hotels can attract more guests and perform business better than the other rated hotels. A similar situation is valid for energy consumption density (Table 4). The EUI of international tourist hotels is substantially higher than that of the other rated establishments. The energy consumed by every guest and every guestroom also show that the international tourist hotel is higher, which might be caused by higher-quality hotels providing high-quality services (swimming pool, spa, gym, laundry, and so on). Hotel enterprises and bed and breakfast facilities are devoted to inbound tourists. This can be proven by the combination of guests they have served. The percentage of foreign guests of all guests in the four rated hotels are 67% in international tourist hotels, 64% in standard tourist hotels, 18% in hotel enterprises, and only 1% in bed and breakfast facilities. Generally, the first two rated hotels prefer receiving foreign guests. To provide a superior service for distinguished guests, hotels must be promoted in many fields. Actually, the threshold of establishing a tourist hotel is substantially more rigid, where equipment, construction material, space, and even high-level services are requested. This might lead to high energy consumption. Although the EUI in Taiwan's international tourist hotels and standard tourist hotels is less than in Hong Kong [7–9], the EUI in Singapore [10,11] and Canada [6], countries close to central and southern Europe [13,20], is higher than the EUI in New Zealand [12]. Compared with other countries, the EUI coincides approximately with the climate condition. Generally, the climate in Taiwan is hot and humid, but is pleasant in the winter (early December to late March). Therefore, it is slightly colder than in Hong Kong and Singapore in the same period. Compared to central or southern Europe, which need both shorter winter heating and summer cooling, the total load is roughly equal to that of longer summer cooling in Taiwan.

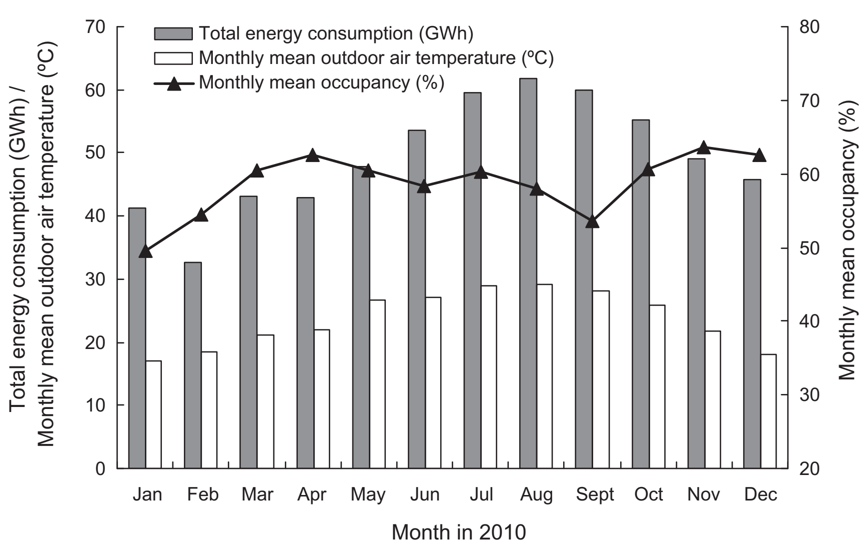


**Fig. 1.** Monthly total energy consumption of all samples investigated, mean outdoor temperature and mean occupancy in 2010.

**Table 3**
Summary of the data collected from surveyed hotels in year 2010.

| Hotel (number of the samples) | Gross floor area ($m^2$) | Construction year | Number of rooms | Number of building stories | Number of workers | Occupancy rate (%) | Average room rate (USD) | Total revenue (1000 USD) | Number of guests (1000) | Energy (MWh) |
|---|---|---|---|---|---|---|---|---|---|---|
| International tourist hotels (45) | <10,000 (7) | Pre-1970 (7) | <200 (6) | <10 (13) | <200 (11) | <50 (3) | <100 (19) | <7000 (6) | <100 (11) | <5000 (13) |
| | 10,000–20,000 (9) | Till 1980 (6) | 200–399 (27) | 11–19 (19) | 200–399 (24) | 50–60 (5) | 100–150 (16) | 7000–15,000 (16) | 100–150 (16) | 5000–10,000 (16) |
| | 20,000–30,000 (8) | Till 1990 (8) | 400–599 (7) | 20–29 (11) | 400–599 (5) | 60–70 (16) | 150–200 (8) | 15,000–30,000 (15) | 150–200 (11) | 10,000–15,000 (12) |
| | 30,000–40,000 (7) | Till 2000 (14) | >599 (3) | >29 (2) | >599 (5) | 70–80 (12) | >200 (2) | 30,000–70,000 (5) | >200 (7) | >15,000 (4) |
| | >40,000 (14) | After 2000 (10) | | | | >80 (9) | | >70,000 (3) | | |
| Average | 30,946 | 1987 | 325 | 17 | 326 | 70.1 | 119 | 22,245 | 140 | 8668 |
| Maximun | 117,484 | 2009 | 856 | 45 | 860 | 89.9 | 228 | 91,637 | 327 | 31,978 |
| Minimun | 5258 | 1956 | 76 | 5 | 80 | 35.5 | 53 | 4124 | 29 | 1587 |
| Standard tourist hotels (19) | <10,000 (2) | Pre-1980 (2) | <100 (2) | <10 (2) | <100 (2) | <60 (5) | <100 (15) | <7000 (5) | <50 (2) | <5000 (12) |
| | 10,000–20,000 (10) | Till 1990 (5) | 100–199 (3) | 11–19 (13) | 100–199 (12) | 60–70 (8) | 100–150 (2) | 7000–15,000 (11) | 50–100 (8) | 5000–10,000 (5) |
| | 20,000–30,000 (3) | Till 2000 (7) | 200–299 (14) | 20–29 (3) | 200–299 (4) | 70–80 (3) | 150–200 (2) | 15,000–30,000 (2) | 100–150 (9) | 10,000–15,000 (1) |
| | >30,000 (4) | After 2000 (8) | | >29 (1) | >299 (1) | >80 (3) | | >30,000 (1) | | >15,000 (1) |
| Average | 21,747 | 1991 | 207 | 14 | 181 | 64.6 | 89 | 11,384 | 95 | 5175 |
| Maximun | 61,669 | 1965 | 288 | 34 | 470 | 83.6 | 178 | 42,411 | 150 | 16,986 |
| Minimun | 5021 | 2008 | 78 | 6 | 34 | 30.6 | 47 | 1421 | 19 | 1208 |
| Hotel enterprises (116) | <3000 (75) | Pre-1980 (43) | <50 (85) | <6 (25) | <20 (35) | <50 (85) | <75 (74) | <700 (75) | <10 (75) | <500 (74) |
| | 3000–10,000 (34) | Till 1990 (44) | 50–99 (29) | 6–9 (48) | 20–49 (49) | 50–60 (15) | 75–100 (38) | 700–1500 (22) | 10–20 (23) | 500–1000 (21) |
| | 10,000–20,000 (5) | Till 2000 (21) | 100–199 (10) | 10–14 (45) | 50–99 (20) | 60–70 (9) | 100–125 (4) | 1500–3000 (12) | 20–30 (12) | 1000–2000 (15) |
| | >20,000 (2) | After 2000 (8) | >199 (2) | 15–25 (8) | >99 (12) | >70 (7) | | >3000 (7) | >30 (6) | >2000 (6) |
| Average | 3521 | 1985 | 45 | 10 | 39 | 48.3 | 71 | 1041 | 12 | 658 |
| Maximun | 26,044 | 2008 | 300 | 23 | 198 | 83.5 | 122 | 8622 | 74 | 6210 |
| Minimun | 472 | 1962 | 8 | 2 | 5 | 33.3 | 41 | 110 | 2 | 59 |
| Bed and breakfast facilities (20) | Avg: 326<br>Max: 454<br>Min:120 | Avg: 1983<br>Newest: 2007<br>Oldest: 1963 | Avg: 5<br>Max: 5<br>Min: 4 | Avg: 3<br>Max: 5<br>Min: 1 | Avg: 7<br>Max: 10<br>Min: 3 | Avg: 44.5<br>Max: 60.2<br>Min: 33.2 | Avg: 69<br>Max: 92<br>Min: 51 | Avg: 224<br>Max: 369<br>Min: 89 | Avg: 1957<br>Max: 3335<br>Min: 1560 | Avg: 47<br>Max: 127<br>Min: 18 |

**Table 4**
Statistical overview of the energy consumption indicators in the hotels investigated.

| Satatistical data of hotels (number of the samples) | Total energy per unit area, EUI ($kWh/m^2$/year) | Total energy per guestroom (MWh/room/year) | Total energy per guestroom-night, (kWh)/(number of room × occupancy × 365) | Total energy per guest-night (kWh)/number of guests |
|---|---|---|---|---|
| International tourist hotels (45) | | | | |
| Average | 280.1 | 26.7 | 104.2 | 61.9 |
| Maximum | 712.1 | 54.1 | 171.1 | 106.1 |
| Minimum | 191.0 | 11.6 | 52.5 | 23.1 |
| Median | 272.8 | 25.1 | 92.7 | 60.7 |
| Standard deviation | 86.5 | 8.7 | 30.4 | 18.7 |
| Coefficient of variation | 29.3% | 33.5% | 29.7% | 31.5% |
| Standard tourist hotels (19) | | | | |
| Average | 237.7 | 25.0 | 106.0 | 54.5 |
| Maximum | 375.8 | 59.0 | 205.4 | 113.4 |
| Minimum | 159.3 | 12.1 | 50.3 | 23.4 |
| Median | 228.7 | 17.5 | 86.1 | 40.9 |
| Standard deviation | 51.9 | 13.3 | 47.2 | 23.4 |
| Coefficient of variation | 21.8% | 55.5% | 46.7% | 46.5% |
| Hotel enterprises (116) | | | | |
| Average | 186.3 | 14.6 | 82.9 | 54.8 |
| Maximum | 382.9 | 34.5 | 194.7 | 108.7 |
| Minimum | 89.7 | 5.9 | 42.4 | 18.0 |
| Median | 175.0 | 15.0 | 81.7 | 48.7 |
| Standard deviation | 60.0 | 5.9 | 27.7 | 20.9 |
| Coefficient of variation | 32.2% | 38.5% | 32.1% | 40.1% |
| Bed and breakfast facilities (20) | | | | |
| Average | 143.6 | 9.4 | 59.1 | 24.0 |
| Maximum | 317.3 | 25.5 | 116.6 | 52.1 |
| Minimum | 94.64 | 4.9 | 21.5 | 8.7 |
| Median | 128.9 | 8.6 | 51.2 | 21.1 |
| Standard deviation | 56.1 | 4.7 | 23.2 | 10.4 |
| Coefficient of variation | 31.2% | 50.0% | 40.3% | 49.3% |

## 4. Results

### *4.1. The secondary determinants of annual energy consumption and EUI*

Pearson correlation coefficients of annual energy consumption and EUI with 24 potential secondary drivers were calculated and are shown in Table 5. For annual energy consumption, most of the variables are significant at the 0.01 level, including building factors (GFA, number of building stories, construction year), hotel rating, hotel location district, guest room conditions (number of guest rooms, average floor area per room, occupancy rate), revenue (rooms, F&B, and total revenue), and the number of employees and guests. The location district variable shows that the hotels located in well-developed cities might consume more energy. For example, hotels in Taipei City (the capital and the most well developed city) consume the most energy than any other city. Significant correlations are reasonable because massive energy consumption of hotels often indicates that the scale of this hotel is substantially greater, better rated, with more employees, a higher occupancy, and considerably more revenue.

The EUI with total potential factors shows fewer significant correlations (number of floors, hotel rating, number of guest rooms, yearly occupancy rate, average room rate, revenue, number of employees, and total guests). Employee density presents a non-significant correlation with EUI, which is different from the reference document of cases in Singapore [10], but the correlation factor 0.132 is extremely close to the limit value at the 0.05 level. In addition, the correlation of the number of domestic guests is the lowest when compared with North America, Japan, and Europe; it somehow appears that hotels serving guests from these regions consume more energy and have a higher EUI. Although the correlation of EUI with variables is lower than annual energy consumption, the relationship is helpful for advanced discussions on establishing multiple regression models.

### *4.2. Multiple regression analysis for predicting annual energy consumption and EUI*

The variables shown in Table 5 are set as independent variables to conduct multiple regression analysis. Theoretically, a greater number of variables contributes more to energy consumption and EUI. However, certain unrelated variables should be deleted. Therefore, variables with significance greater than 0.05 were deleted. Table 6 shows that multiple regression models are based on variables and their $R^2$ coefficient, which are 0.931 and 0.620, respectively. The $R^2$ coefficient 0.931 refers to the annual energy consumption being set as an independent variable, and the number of guest rooms, gross floor area, average room rate, total revenue, occupancy rate, and number of building stories being set as dependent variables. Whereas the $R^2$ coefficient 0.620 refers to the EUI being set as an independent variable, the occupancy rate, gross floor area, room rate, and building construction year are set as dependent variables. This finding is not perfect because of the large deviation in certain cases, but the $R^2$ value is acceptable. The significance of the two models is both $0.000 < 0.05$, which indicates a regression relation between the dependent and independent variables. Two regression models are shown in Equations 1 and 2. The coefficient of the adjusted $R^2$ coefficient is 0.928 and 0.612, which should be reliable. Regarding the prediction of annual energy consumption (AEC), the number of guest rooms had the most influence, followed by the gross floor area; both can explain the 91.2% variation of annual energy consumption. The last variable, the number of floors, can only add 0.1% to the explanation; therefore, Equation 1 excluded the variable. Regarding the prediction of EUI, the occupancy rate contributes most to the explanation in variation, followed by the gross floor and average room rate, in that order. The three variables can explain 60.6% of the variation. In addition, both the standardized coefficient of gross floor area and construction year are negative, which indicates that a higher gross floor area signifies a lower EUI. Newly constructed hotels also perform lower EUI.

**Table 5**
The pearson correlations of secondary energy drivers for energy use and energy use intensity.

| Variable name | Description | Pearson correlation | |
|---|---|---|---|
| | | Energy consumption | EUI |
| GFA | Gross floor area | 0.921** | 0.165* |
| STORY | Number of building stories | 0.684** | 0.252** |
| CONYEAR | Building construction year | 0.236** | −0.151* |
| RATING | Hotel rating | 0.738** | 0.415** |
| ZONE | Hotel location district | 0.269** | 0.283** |
| ROOM | Number of guest rooms | 0.925** | 0.296** |
| GFARM | Gross floor area per guest room | 0.508** | 0.006 |
| PTDINING | Percent of GFA for dining facilities | 0.140* | 0.133 |
| PTRETAIL | Percent of GFA for retail shops | 0.148* | 0.125 |
| OCPRATE | Yearly occupancy rate | 0.638** | 0.712** |
| ROOMRATE | Average room rate | 0.465** | 0.623** |
| ROOMRVN | Room revenue | 0.918** | 0.282** |
| F&BRVN | Food & beverage revenue | 0.818** | 0.261** |
| TOTALRVE | Total revenue | 0.854** | 0.270** |
| WORKER | Number of workers | 0.901** | 0.315** |
| WORKERDST | Worker density | −0.039 | 0.132 |
| GUESTT | Number of total guests | 0.929** | 0.321** |
| GUESTFIT | Guests of foreign independent tourist | 0.860** | 0.250** |
| GUESTGROUP | Guests of group | 0.776** | 0.322** |
| GUESTDMT | Guests from domestic | 0.488** | 0.175* |
| GUESTSCHN | Guests from China | 0.552** | 0.183** |
| GUESTNA | Guests from North America | 0.849** | 0.219** |
| GUESTJPN | Guests from Japan | 0.717** | 0.340** |
| GUESTEU | Guests from Europe | 0.827** | 0.234** |

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

Both regression equations are applicable only to Taiwan because the downloaded data only represent local characteristics. All the variable values of the samples are provided in the two proposed equations, which leads to the prediction of annual energy consumption and EUI. Compared to actual values, the prediction values represent 19% and 13% inaccuracy for actual energy consumption and EUI, respectively. In an attempt to use the proposed equations with the average of international tourist hotels (Table 3), the results were 8628 MWh, which is close to the actual value of 8668 MWh. The outcome indicates that the regression equations should be acceptable. Reviewing the variable values of all samples sequentially by case, factors that can relatively improve the accuracy of the proposed correlations exist. For example, hotels located in well developed cities often consume more energy than those located in the countryside. International tourist hotels in Taipei consume energy upward by 7% on average than in Taichung. However, the location influences the accuracy for a few hotels because the significance is greater than 0.05. Thus, the location was not incorporated into the prediction models.

Furthermore, renovations could also play an important role in the energy consumption of hotels. Energy consumption could be reduced by 20–40% through installing more efficient lighting or air conditioning without affecting hotel functionality [25]. Even a keycard ensuring that all electrical appliances are switched off when guestrooms are unoccupied could help save 1147 kWh/year per room [17]. A recent study focusing on hotels in Taiwan also indicated that a number of local hotels have adopted energy conservation measurements including air conditioning temperature adjustment, heat pump systems, energy-saving lighting, efficient refrigeration facilities, auto-sensing devices, and energy usage monitoring systems [26]. Although they did not audit the benefits of efficient equipment, these measures should help reduce energy consumption. However, this study considered the construction date of the hotel instead of renovations, which has led to the difficulty in assessing renovations. Some hotels revamp lobbies and public spaces, whereas others focus on dated guest rooms, and only certain parts because of limited budgets. Therefore, renovation might be a more important variable than construction, but delimiting is difficult to quantify accurately. In general, older hotels

**Table 6**
Multiple regression analysis of energy consumption and EUI.

| Priority of independent | Coefficient of *R* | Coefficient of determination ($R^2$) | $R^2$ change ($\Delta R$) | *F* value | *F* change | Standardized coefficients |
|---|---|---|---|---|---|---|
| **Dependent variable: annual energy consumption** | | | | | | |
| ROOM | 0.925 | 0.856 | 0.856 | 1177.9 | 1177.9 | 0.263 |
| GFA | 0.955 | 0.912 | 0.056 | 1016.7 | 124.0 | 0.474 |
| ROOMRATE | 0.960 | 0.922 | 0.011 | 774.7 | 26.6 | 0.054 |
| TOTALRVE | 0.962 | 0.926 | 0.004 | 611.4 | 10.4 | 0.161 |
| OCPRATE | 0.964 | 0.930 | 0.004 | 514.5 | 10.3 | 0.080 |
| STORY | 0.965 | 0.931 | 0.001 | 436.4 | 4.1 | 0.056 |
| **Dependent variable: EUI** | | | | | | |
| OCPRATE | 0.712 | 0.506 | 0.506 | 203.1 | 203.1 | 0.657 |
| GFA | 0.748 | 0.560 | 0.054 | 125.5 | 24.1 | −0.221 |
| ROOMRATE | 0.779 | 0.607 | 0.046 | 100.8 | 23.2 | 0.273 |
| CONYEAR | 0.787 | 0.620 | 0.013 | 79.4 | 6.6 | −0.120 |

certainly consume more energy than new hotels. Thus, the date of construction was selected for incorporation into the EUI prediction model, but it is the last priority of the independent variables, and can explain only 1.3% of EUI variation.

$$\mathrm{AEC\,(kWh)} = -2,196,814 + 8982 \times \mathrm{ROOM\,(number)} + 127 \times \mathrm{GFA\,(m^2)} + 7068 \times \mathrm{ROOMRATE\,(USD)} + 0.0495 \times \mathrm{TOTALRVE\,(USD)} + 2,901,240 \times \mathrm{OCPRATE} \cdots (1)\, R^2 = 0.928$$

$$\mathrm{EUI\,(kWh/m^2/year)} = 1630 + 373.76 \times \mathrm{OCPRATE} - 0.00104 \times \mathrm{GFA\,(m^2)} + 0.738 \times \mathrm{ROOMRATE\,(USD)} - 0.829 \times \mathrm{CONYEAR\,(A.D.)} \cdots (2)\, R^2 = 0.612$$

To investigate the accuracy of the proposed equations in predicting annual energy consumption and EUI for different locations, this study tested them on other samples and different locations. Two tourist hotels were inaugurated in early 2010 in Taiwan, and the collected operations data spanned from July 2010 to June 2011. The prediction values represent −6% to +7% when compared to actual annual energy consumption and EUI. In addition, the equations were also applied to two Taiwan chain hotels located in Guangzhou and Shanghai, China. The prediction values represent −4% and −6% in Guangzhou, and −7% and −4% in Shanghai. This study also used published data from international literature [8,10,12,20]; certain values of variables were published, but lacked data that were empirical information. The prediction values represent −38% and −36% in Hong Kong, −19% and −14% in Singapore, −16% and −10% in Europe, but +14% and +30% in New Zealand. The outcome implies to a degree that the prediction might be a lower value in hotter and colder areas, but a higher value in comfortable areas. In other words, applying empirical correlations to different locations leads to large deviations of over 30%.

## 5. Conclusion

Four types of hotels with a total number of 200 hotels are available according to a nationwide survey in Taiwan. The samples include the highest rated international tourist hotels, second highest rated standard tourist hotels, third highest rated hotel enterprises, and basic rated bed and breakfast facilities. Considering hotel type, sample number, or the scope of location district, it is the largest energy consumption survey ever conducted in Taiwan. Electricity predominantly comprises annual energy consumption, which accounts for 84% of total energy on average. This ratio is lower than investigated in Hong Kong (73%) in 1998 and proximate to that of Singapore (85%) in 2008. This increase may show that electricity usage has become more convenient and safe in the last decade, or that electricity usage is more popular in Taiwan than in Hong Kong. The Pearson correlation coefficient of electricity consumption and annual energy consumption is 0.94. Mean EUI of the four rated hotels is 280.1, 237.7, 186.3, and 143.6 kWh/m$^2$/year.

In the end, two simple regression models were developed for predicting annual energy consumption and energy use intensity. The coefficient of $R^2$ and its significance demonstrate that the model is reliable. Mean energy consumption per guest room of the four rated hotels is 26.7, 25.0, 14.6, and 9.4 MWh/room/year. Considering all the registered hotels, this mean value indicates that the hotel industry consumes at least 2621 GWh annually, which is approximately 1.1% of the total energy consumed by the nation. Furthermore, because of the large increase in number of tourists from China, the hotels grew rapidly (up to 10–20% annually in the past three years). Energy conservation must be deliberated on immediately but with caution, especially in Taiwan, where energy resources rely mostly on import.

For in-depth analysis of hotel energy consumption, a number of investigations are still required. First, increasingly more hotels endeavor to raise food and beverage revenue, shopping centers, and even combine them with department stores. Therefore, energy consumption is becoming considerably more difficult to evaluate. Representative hotels must be selected to conduct more inter-group comparisons. To separate every purpose and energy consumption, this should be helpful to determine the combination of hotel energy consumption. Second, certain energy consumption information of major equipment (air conditioning, ventilation, lighting, vertical transportation, cooking, water heating, and so on) must be measured. Installation of energy meters in hotels and continuous monitoring of their readings should help obtain more quantitative evidence on energy requirements, which will enhance our understanding of where and how energy is consumed.

This study has provided a number of suggestions for hotel managers who face decisions on how to reduce energy consumption. First, the occupancy rate is the most important variable of the EUI prediction regression model, and is also a variable of total energy prediction. Managers should adopt constructive measures that include gathering the same group of guests to a same floor to reduce the air conditioning load especially during the high seasons, and lower the air conditioning load during room service time especially in the afternoon to avoid the penalty for rush hour by power plants. Second, the EUI of newly constructed hotels is often lower than that in older hotels; the EUI is determined mainly based on the strength of new and more efficient equipment. A number of investigations have provided evidence that efficient lighting and air conditioning are factors for saving energy. Third, hotel refurbishment has been proven to have considerable potential for energy conservation in hotels that were analyzed by the literature. This could help reduce energy consumption by using numerous measures that are considered to yield considerable benefits [17]. The energy conservation potential of hotels in the Mediterranean was estimated to reach even 50% [15]. Therefore, hotels should list priorities based on the benefits of renovation and execute the energy conservation plan as soon as possible. Finally, certain local government organizations for energy counseling and conservation should participate in these plans. Consultant groups may provide some measures after investigating hotels. In fact, certain hotels in this survey have improved after counseling, and the financial cost was worth the enhancement. The results of this study could serve as a useful reference for hotel managers, investors interested in hotel construction, and local government authorities who are preparing to establish energy conservation codes for the hotel industry.

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