A Bottom-up Method to Assess Energy Consumption of Main Departments in Five-star Hotels in China

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Abstract

Five-star hotels are one of the most energy intensive building types in China. Previous energy evaluation methods for hotel buildings do not assess the multi-faceted nature of energy performance in hotel buildings. This study investigates the energy usage of 46 five-star hotels in China from 2013 to 2016. A bottom-up method is presented to separately evaluate the main functional areas of a hotel, including guestrooms, laundry rooms, and kitchens. This method defines the main influencing factors on energy consumption and quantitatively predicts the energy-saving potential of the given department in a hotel.

Introduction

Decreasing the energy usage of hotel operations is essential for sustainable development and operational cost-savings. The hospitality industry in China has experienced rapid expansion, with the number of five-star hotels increasing from 242 in 2004 to approximately 800 in 2014 (National Tourism Administration, 2014). Energy consumption in hotel buildings has also significantly increased with high quality hotels now ranked second for energy-intensive large public buildings in China (Building Energy Conservation Research Center, 2011). Due to rising energy prices and consumption needs, hotels are giving greater attention to energy performance and environmental impact. In 2014, China published a national standard for building energy consumption (Building Energy Conservation Research Center, 2016). However, this standard only provided a guide for total hotel energy consumption target levels rather than comprehensively evaluating energy consumption. For example, the impact of operating factors such as occupancy rate was not included in this standard. Additionally, previous evaluation systems for hotel buildings only focused on total energy consumption rather than providing effective energy saving guidelines. Therefore, it is important to develop a method that adequately assesses the multi-faceted nature of energy performance in hotel buildings.

Previous studies surveyed the energy performance of hotels worldwide. These studies can be divided into three categories: energy audit, energy index and regression analysis. Figure 1 summarizes these energy surveys (Becken S, 2001; Bohdanowicz P, 2007; Chan W W, 2002; Deng S M, 2000; Farrou I, 2012; Önüt S, 2006; Priyadarsini R, 2009; Rosselló-Batle B, 2010; Santamouris M, 1996; Trung D N, 2005; Wang J C, 2012; Xin Y, 2012; Zmeureanu R G, 1994). Per these reports, total energy consumption significantly varied among the different hotels. The factors influencing energy use included climate, location, hotel scale, service and management levels, and building equipment (Becken S, 2001; Bohdanowicz P, 2007; Chan W W, 2002; Deng S M, 2000; Deng S M, 2002A; Deng S M, 2002B; Deng S M, 2003; Farrou I, 2012; Önüt S, 2006; Priyadarsini R, 2009; Rosselló-Batle B, 2010; Santamouris M, 1996; Trung D N, 2005; Wang J C, 2012; Xin Y, 2012; Zmeureanu R G, 1994; Wei Z, 2011).

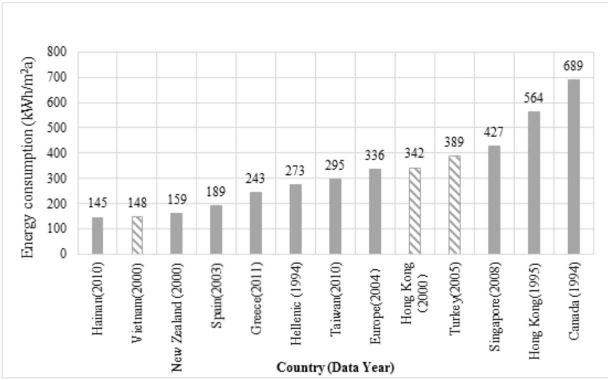


Figure 1: Average energy consumption for hotel buildings worldwide (Stripes represent electricity only)

Previous literature typically focused on total energy consumption, heating, and air conditioning systems (Deng S M, 2000; Hui S C M, 2010; Trung D N, 2005). While this is a common energy analysis method, it is not adequate for hotel buildings due to the wide range of operational sectors involved, including guestrooms, food and beverage services, laundries, and other guest-catering areas (Deng S M, 2000). Therefore, it was necessary to develop a systematic evaluation method that could separately assess different functional areas in hotels and determine areas with the most energy-saving potential.

Methods

Forty-six five-star hotels were surveyed, comprising 29 business hotels and 17 resort hotels. These hotels were located across four main climate zones in China, including Severe-Cold (5 hotels), Cold (11 hotels), Hot-Summer and Cold-Winter (HSCW) (16 hotels), and Hot-Summer and Warm-Winter (HSWW) (14 hotels).

Firstly, basic information was collected, including construction information, equipment operating records, energy consumption data, and business data. Construction information included story height, floor area, and number of guestrooms. Operating information was collected for each of the main energy-consuming systems and departments, including the operating schedule of the air conditioning, lighting, kitchen, restaurants, and laundry. Energy consumption data was collected from various energy metering systems, including the monthly sub-metering data of electricity, gas, and municipal heating consumption. Business data in the current study referred to occupancy rate, number of food covers (i.e., the number of meals served in a hotel, Deng S M (2003)), and the laundry load.

After collecting the raw data, an overview of total energy consumption identified three departments with the highest potential for energy savings: guestrooms, food and beverage (F&B) services, and laundry. Guestrooms comprised a large amount of the total hotel area. For example, in China, an average of 50 to 60 % of the gross floor area in a five-star hotel is the guestrooms. Energy consumption of guestrooms included electricity for room lighting, corridor lighting, room air conditioning, and other powered devices within the guestrooms.

For food and beverage services, a typical five-star hotel in China has two main restaurants: all-day-dining (ADD) and Chinese. There are often one or two specialty restaurants as well. Kitchens are separately constructed to cater for the different demands of the different restaurants. The kitchen setup typically includes a Western kitchen, a Chinese kitchen, several auxiliary kitchens, and some functional rooms. In addition to the guest restaurants, there are also a staff canteen and a staff kitchen. Per the research for this paper, F&B services in five-star hotels comprised approximately 20 % of total energy consumption with the main energy form being natural gas. Therefore, this paper explored the relationship among occupancy rate, the number of food covers, and gas consumption. For the laundry department, laundry steam is an integral part of energy consumption. Hence, this paper also presents an equation to estimate the energy consumption of laundry steam.

Firstly, energy models for the above three departments are presented. Then, the models are validated by comparing the predicted values with actual energy consumption derived from the survey.

Discussion and result analysis

1. Total Energy Consumption

Figure 2 shows an overview of the annual energy consumption of the 46 five-star hotels. To unify the units of measurement, the electricity equivalent method is used to convert the different energy categories into electricity per their exergy level (Jiang Y, 2010). The annual energy consumption ranges from 100 to 300 kWh/m^{2}a, with most results ranging from 150 to 220 kWh/m^{2}a. Across all 46 hotels, the average energy consumption is 187 kWh/m^{2}a.

Annual energy consumption significantly varies among the hotels due to a range of different energy systems, operational modes, and climate zones. To address these differences, specific energy sectors are individually analyzed. Taking Hotel COLD 5 as an example, air conditioning, guestrooms and F&B kitchens comprise 60 % of total electricity usage while space heating, domestic hot water, and laundry steam comprise more than 90 % of natural gas usage, as shown in Figure 3 and 4. Thus, subsequent analyses focus on the three highest energy-consuming departments in a five-star hotel: guestrooms, F&B services, and laundry.

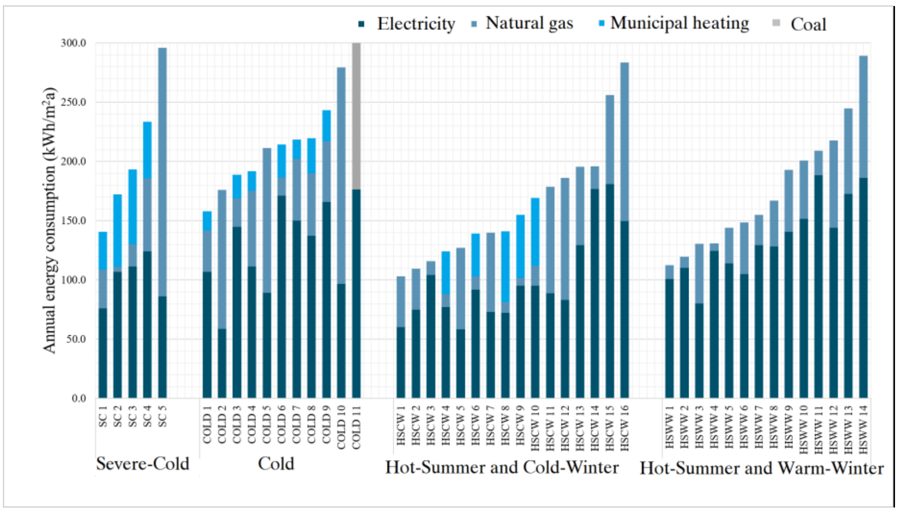


Figure 2: Annual energy consumption of five-star hotels in China

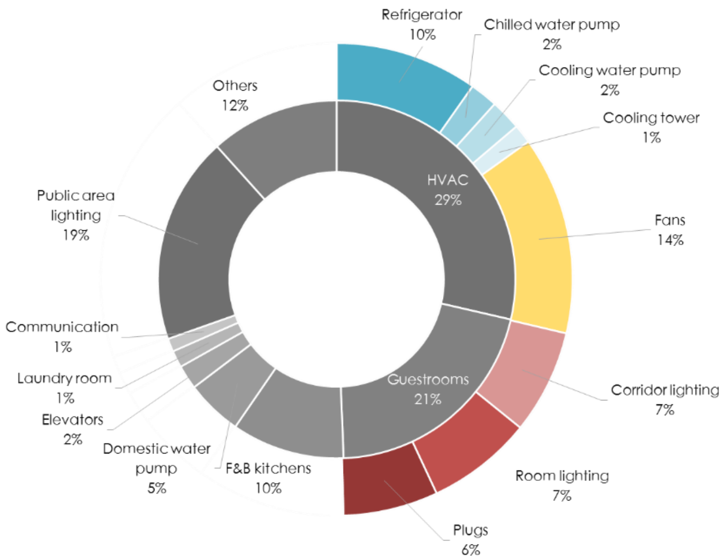


Figure 3: Electricity bottom-up analysis of Hotel COLD 5

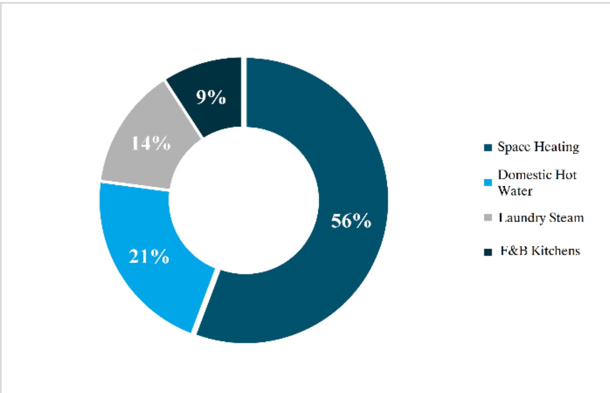


Figure 4: Natural gas bottom-up analysis of Hotel COLD 5

2. Guestrooms

As it's mentioned before, energy consumption of guestrooms included electricity for room lighting, room air conditioning, other powered devices within the guestrooms and corridor lighting.

2.1 Room lighting

Electricity consumption of lighting in a standard guestroom can be expressed as:

$$E_{L_{gr}} = D_{L_{gr}} \times A_{gr} \times \Delta T_{(L_{gr,i})} \times \zeta_{L_{gr}} \tag{1}$$

where $E_{L_{gr}}$ is the lighting electricity consumption of a standard guestroom per day, kWh/day; $D_{L_{gr}}$ is the lighting power density of a standard guestroom, kW/m^2; A_{gr} is the area of a standard guestroom, m^2; $\Delta T_{(L_{gr,i})}$ is the average operating time of lighting in guestrooms per day, h/day; $\zeta_{L_{gr}}$ is the concurrent lighting factor, which represents the portion of lighting in use compared with total available guestroom lighting.

The guest survey shows that the average operating time of lighting in guestrooms is 12 h per day and that concurrent lighting factor is 40 %. These values can be substituted into Eq. (1):

$$E_{L_{gr}} = 4.8(h/day) \times D_{L_{gr}} \times A_{gr} \tag{2}$$

Besides, the hotel survey shows that the average lighting power density of a standard guestroom is 25 W/m^2; as such, $D_{L_{gr}}$ is taken as 25 W/m^2 when its precise value is unknown.

2.2 Room air conditioning

Electricity consumption for room air conditioning refers to the electricity consumption of the fan coil units. Per the survey, a standard guestroom is equipped with one fan coil unit. The fan coil unit normally operates 24 hours to maintain a comfortable indoor environment. Table 1 lists the operating modes and electricity consumption of a fan coil unit in a standard guestroom.

Table 1: Electricity consumption of fan coil unit in standard guestroom

Speed	Air flow (m^3/h)	Power (W)	Service time (h/day) (Average value)	Electricity consumption (kWh/day) (Average value)
High	1020	90	2	0.18
Medium	850	60	10	0.60
Low	530	40	12	0.42
Total				1.20

Therefore, the electricity consumption of the fan coil unit in a standard guestroom is predicted as $E_{FCU_{gr}} = 1.2$ kWh/day.

2.3 Other powered devices

In addition to lighting and air conditioning, five-star hotels also offer other powered devices in guestrooms, such as televisions, electric kettles, refrigerators, and hair driers. Zhang X Q (2010) investigated the use of powered devices in a standard guestroom and Ye J Y (2013) listed device electricity consumption for a standard guestroom. Integrating these results with the current study, Table 2 lists the usage time and electricity consumption of other powered devices in a standard guestroom. Hence, the electricity consumption of other powered devices in a standard guestroom is predicted as $E_{PD_{gr}}$ =3.8 kWh/day.

Table 2: Electricity consumption of other powered devices in standard guestroom

Devices	**Power (W)**	**Quan -tity**	**Service time (h/day) (Average value)**	**Electricity consumption (kWh/day) (Average value)**
Hair drier	1500	1	0.3	0.45
Electric kettle	2000	1	0.5	1.00
Television	120	1	5	0.60
Refrigerator	60	1	24	1.44
Exhaust fan	25	1	12	0.30
Total				3.79

2.4 Corridor lighting

Electricity consumption of lighting in the corridor can be expressed as:

$$E_{L_{gc}} = D_{L_{gc}} \times A_{gc} \times \Delta T_{(L_{gc,i})} \times \zeta_{L_{gc}} \quad (3)$$

where $E_{L_{gc}}$ is the lighting electricity consumption of the corridor per day, kWh/day; $D_{L_{gc}}$ is the lighting power density of the corridor, kW/m^2; A_{gc} is the area of the corridor, m^2; $\Delta T_{(L_{gc,i})}$ is the average operating time of lighting in the corridor per day, h/day; and $\zeta_{L_{gc}}$ is concurrent lighting factor in the corridor.

Lai H D (2010) and Shen X (2012) suggested that the corridor area could be estimated by the area of the guestrooms using the following equation:

$$A_{gc} = 0.3 \times N_{gr} \times A_{gr} \quad (4)$$

where N_{gr} is the number of standard guestrooms.

The survey (managers) shows that the average operating time of lighting in the corridor is 24 h per day and that concurrent lighting factor is 60 %. Substituting these values and Eq. (4) into Eq. (3) yields:

$$E_{L_{gc}} = 14.4\ (h/day) \times 0.3 \times D_{L_{gc}} \times N_{gr} \times A_{gr} \quad (5)$$

The hotel survey also shows that the average lighting power density of the corridor is 10 W/m^2, so $D_{L_{gc}}$ can be taken as 10 W/m^2 when its value is unknown.

2.5 Electricity consumption prediction model for guestrooms

The annual electricity consumption of a five-star hotel guestroom district is expressed as:

$$\mathrm{E_{GR}} = 365 \times [N_{gr} \times OCP \times \left(E_{L_{gr}} + E_{FCU_{gr}} + E_{PD_{gr}}\right) + E_{L_{gc}}]$$

$$= 365 \times [N_{gr} \times OCP \times (4.8 \times D_{L_{gr}} \times A_{gr} + 5.0) + 4.32 \times D_{L_{gc}} \times N_{gr} \times A_{gr}] \quad (6)$$

where $\mathrm{E_{GR}}$ is the annual electricity consumption of a five-star hotel guestroom district, kWh; OCP is the annual average occupancy rate; $D_{L_{gr}}$ is 0.025 kW/m^2 and $D_{L_{gc}}$ is generally 0.01 kW/m^2.

The actual annual electricity consumption of the guestroom area for 20 five-star hotels is compared to a predicted value produced by the equation derived from the results of this study. The actual and predicted values are compared in Figure 5 and 6, providing evidence that the electricity consumption prediction model for guestrooms has a high degree of accuracy.

The energy-consumption evaluation model for guestrooms proposed in this paper conforms to the five-star hotel energy metering data. As such, it can be used to analyze the source of guestroom energy-consumption and explore energy-saving potential. Taking Hotel HSCW 9 as an example, the actual electricity consumption is much lower than the predicted value because the hotel switches to an energy-saving lamp system in the guestroom district, which reduces electricity consumption by 300,000 kWh/yr.

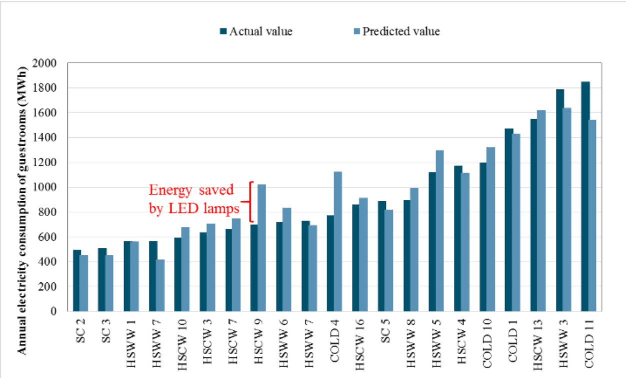


Figure 5: Comparison of actual value and value predicted under electricity consumption model for guestrooms

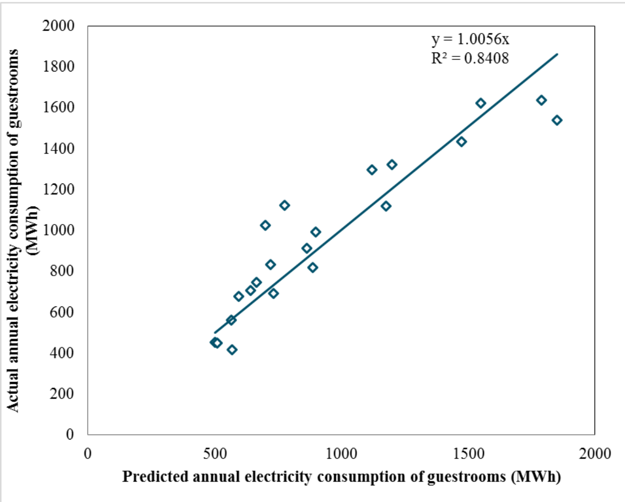


Figure 6: Prediction accuracy of electricity consumption model for guestrooms

3. Food and Beverage Service

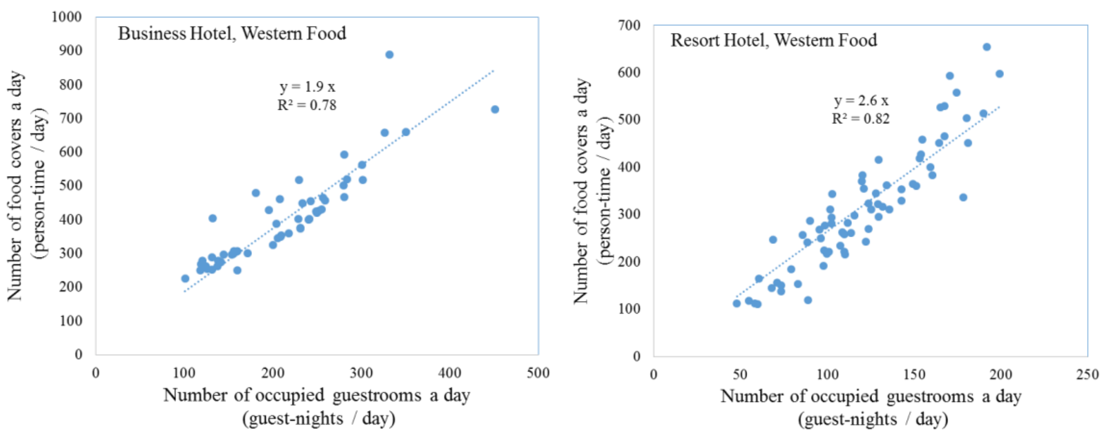
Focused on the demand side, this paper explored the relationship among occupancy rate, the number of food covers, and gas consumption of F&B services.

3.1 Number of food covers

Deng S M (2003), Bohdanowicz P (2007), Gao X (2007), Hui S C M (2010) and Santamouris M (1996) take the number of food covers as the key influencing factor for energy consumption of F&B services. The food cover data from 12 hotels is obtained then used to explore the relationship between the number of food covers and the number of occupied guestrooms, which contributes to the F&B services analysis for energy consumption. The relationship can be expressed as:

$$N_{food-covers} = \lambda_{food-covers} \cdot N_{gr} \cdot OCP \tag{7}$$

where $N_{food-covers}$ is the number of food covers a day in a five-star hotel, person-time/day; $\lambda_{food-covers}$ is the food-cover coefficient, which describes the number of food covers per unit occupied guestroom, person-time/guest-night. Figure 7 shows the results of the 12 hotels. The authors note that the number of food covers for Western food is more relevant to the number of occupied guestrooms than that for Chinese food because five-star hotels serve a daily Western buffet breakfast. Also, the number of food covers for Chinese food in resort hotels is more relevant to the number of occupied guestrooms than that in business hotels because business hotels are generally in downtown areas that provide more external F&B options (i.e. restaurant proprietors outside of the hotel) for hotel guests. Based on the above analysis, Table 3 lists the proposed food-cover coefficient values.



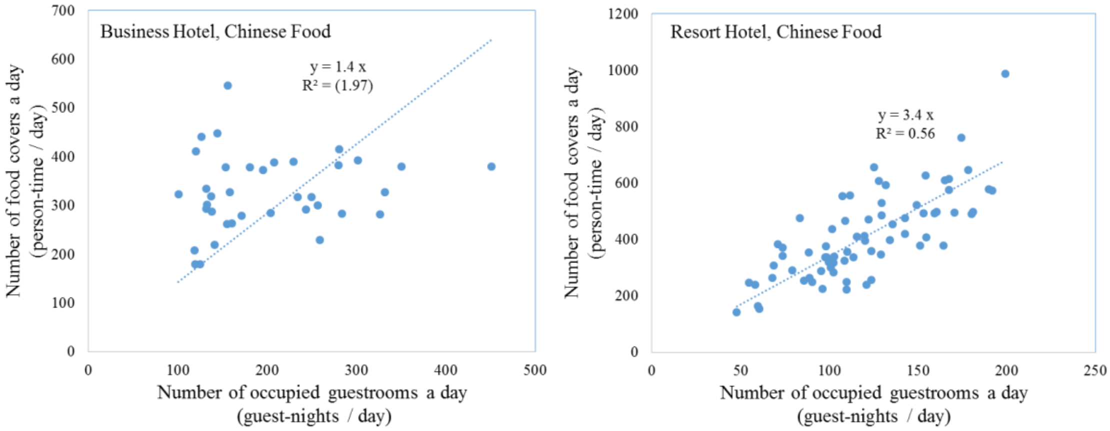


Figure 7: Relationship between number of food covers and number of occupied guestrooms

Table 3: Proposed values of food-cover coefficient

person-time / guest-night	$\lambda_{food-covers}$ for Western food	$\lambda_{food-covers}$ for Chinese food	Total
Business Hotel	1.9	1.4	3.3
Resort Hotel	2.6	3.4	6.0

3.2 Natural gas consumption prediction model for food and beverage services

Natural gas consumption data is obtained for 16 hotels, with six of the hotels also providing food-cover data for the same period. The relationship between natural gas consumption and the number of food covers in the six hotels is expressed as:

$$G_{F\&B} = 0.37 \times N_{food-covers} \times 365 \qquad (8)$$

where $G_{F\&B}$ is the annual natural gas consumption for F&B services in a five-star hotel, m^3. Figure 8 shows the fitting curve.

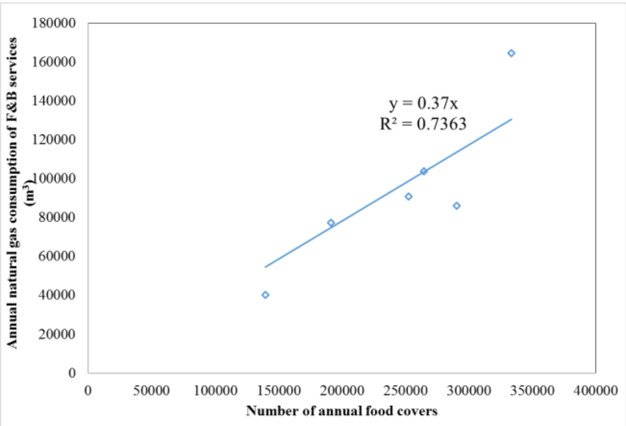


Figure 8: Fitting curve of natural gas consumption and number of food covers

Substituting Eq. (7) into Eq. (8) yields:

$$G_{F\&B} = 0.37 \times \lambda_{food-covers} \cdot N_{gr} \cdot OCP \times 365 \qquad (9)$$

The prediction model is verified by using it to predict the natural gas consumption for F&B services in the remaining 10 hotels. Figure 9 shows the prediction results, which verify that the model reasonably predicts the natural gas consumption for F&B services based on the number of food covers.

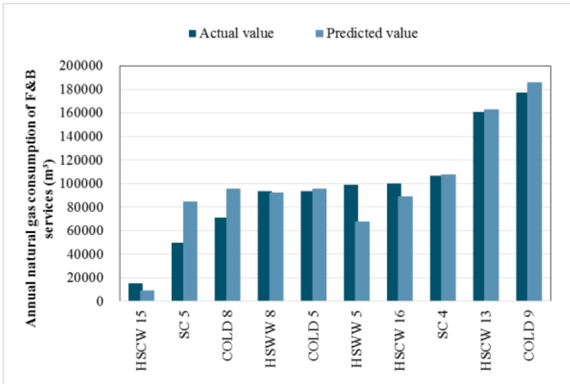


Figure 9: Comparison of actual and predicted values under natural gas consumption model for F&B services

4. Laundry

Bohdanowicz P (2007), Deng S (2003), Hui S C M (2010) and Priyadarsini R (2009) show that the energy consumption for laundry in five-star hotels is directly affected by the laundry load. As such, this aspect is considered first.

4.1 Laundry load

The laundry load in a five-star hotel mainly includes linen and uniforms. Linen includes rooms (bed sheets, quilt covers and towels), F&B (napkins and tablecloths) and recreation (towels). Per the research for this paper, linen comprises 80-90 % of the total laundry load. Uniforms include staff uniforms and guest clothing. Generally, guest clothing comprises only 2-5 % and staff uniforms comprise 10-15 % of the total laundry load.

Given that linen comprises the largest proportion of the laundry load and that it is highly correlated to the occupancy rate, the laundry load is also correlated to the occupancy rate. The laundry load data of ten hotels are collected and a data analysis shows that six of the hotels have a high correlation between laundry load and the number of occupied guestrooms. Based on the data analysis of the six above-mentioned hotels, the correlation can be expressed as:

$$Y_{laundry-load} = 10 \times N_{gr} \times OCP + 12900 \qquad (10)$$

where $Y_{laundry-load}$ is the laundry load of a five-star hotel over a one month period, kg/month. Figure 10 shows the fitting curve.

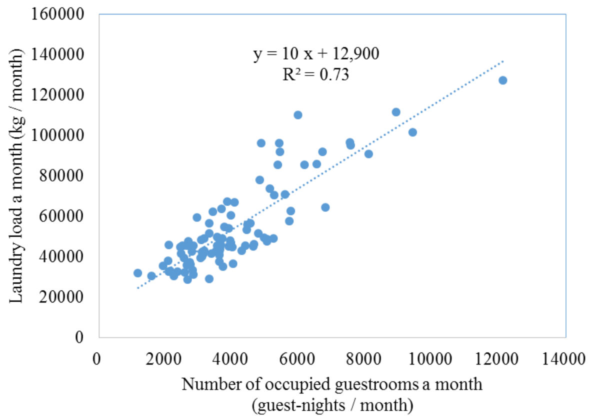


Figure 10: Fitting curve of laundry load and number of occupied guestrooms

4.2 Electricity consumption prediction model for laundry

Five of the researched hotels provide both laundry load data and electricity consumption data, as listed in Table 4. Figure 11 shows the fitting curve of the electricity consumption and laundry load. Here, the derived electricity consumption per unit laundry load is 0.092 kWh/kg. The electricity consumption prediction model for laundry is expressed as:

$$E_{laundry} = 0.092\, Y_{laundry-load} \times 12$$
$$= 0.092\ (10 \times N_{gr} \times OCP + 12900) \times 12 \qquad (11)$$

where $E_{laundry}$ is annual electricity consumption of laundry in a five-star hotel, kWh.

To verify the prediction model in Eq. (11), it is used to predict the electricity consumption for laundry in the other 11 hotels which only provides laundry electricity consumption data but no laundry load data. Figure 12 shows the results, which verify that the relative error between the predicted value and the actual value of the laundry electricity consumption is within 20 % (excepting Hotel HSWW 3). Hence, the model can reasonably predict the electricity consumption for laundry.

Table 4: Summary of laundry load data and electricity consumption data

Hotel code name	Annual laundry load (kg)	Annual electricity consumption (kWh)	Electricity consumption per unit laundry load (kWh/kg)
COLD 5	536851	42705	0.080
HSWW 5	1140921	120000	0.105
HSWW 1	489441	34800	0.071
HSCW 7	808974	63012	0.078
HSCW 12	149896	17772	0.119
Average			0.092

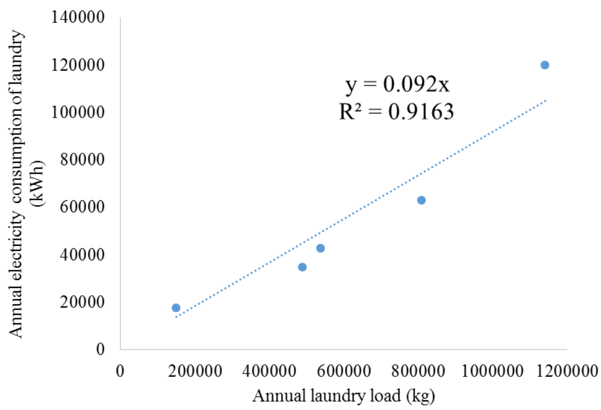


Figure 11: Fitting curve of electricity consumption and laundry load

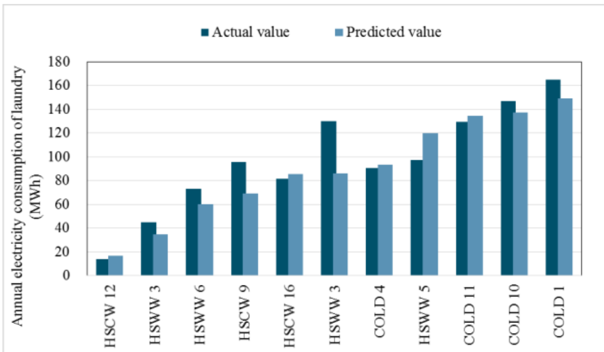


Figure 12: Comparison of actual and predicted values under electricity consumption model for laundry

4.3 Energy consumption prediction model for laundry steam

Four of the researched hotels have both laundry load data and laundry steam consumption data, as listed in Table 5. The derived laundry steam consumption per unit laundry load is 2.2 kg(steam)/kg(clothes). The laundry steam consumption prediction model is expressed as:

$$Y_{laundry-steam} = 2.2 \times Y_{laundry-load} \times 12$$
$$= 2.2 \ (10 \times N_{gr} \times OCP + 12900) \ \times 12 \quad (12)$$

where $Y_{laundry-steam}$ is the annual laundry steam consumption in a five-star hotel, kg. Per Shen W D (1979), the energy consumed when heating ambient temperature water to 0.5 MPa saturated steam can be calculated by the following equation:

$$E_{laundry-steam} = Y_{laundry-steam}(h_2 - h_1)/\eta_{steam} \quad (13)$$

where $E_{laundry-steam}$ is the annual energy consumption of laundry steam in a five-star hotel, kJ; h_1 is the enthalpy of ambient temperature water, kJ/kg, with ambient temperature set at 20 ℃ such that $h_1 = 80.8\ kJ/kg$; h_2 is the enthalpy of 0.5 MPa saturated steam such that $h_2 = 2748\ kJ/kg$; and η_{steam} is the steam system efficiency, which is 0.8 per Lin C Y (2013).

The laundry steam consumption data from 12 hotels shows that five of them use steam condensation heat recovery or flue gas condensation heat recovery technologies. Per Eq. (13), Figure 13 compares actual and predicted values under the energy consumption model for laundry steam. The red blocks represent hotels that do not use heat recovery technology; here, the predicted values approximate the actual values. The blue blocks represent hotels that use heat recovery technology; here the actual values are 28 % lower than the predicted values. This difference is taken to be the energy-saving potential of the heat recovery technology. Data shown in Figure 14 can also be used to derive the above-mentioned conclusions. Hence, in addition to predicting the energy consumption for laundry steam, the model also provides the energy consumption criterion required to analyze the energy-saving potential of relevant energy conservation measures.

Table 5: Summary of laundry load data and laundry steam consumption data

Hotel code name	Annual laundry load (kg)	Annual laundry steam consumption (kg)	Laundry steam consumption per unit laundry load (kg(steam)/kg(clothes))
HSCW 7	808974	1571333	1.9
HSWW 1	489441	1131500	2.3
HSWW 2	592664	1615059	2.7
HSWW 5	1140921	2089000	1.8
Average			2.2

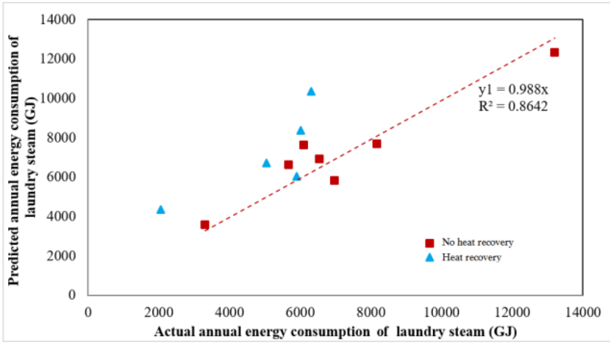


Figure 13: Comparison of actual and predicted values under energy consumption model for laundry steam

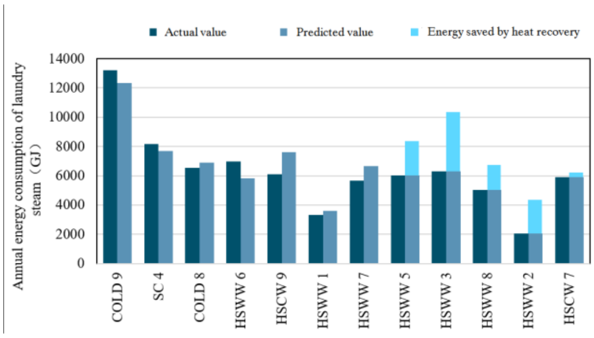


Figure 14: Energy-saving potential of heat recovery technology

Conclusion

Five-star hotels are one of the most energy intensive buildings in China. However, previous energy consumption evaluation methods do not adequately address the multi-faceted nature of energy performance in hotel buildings. This paper presents a bottom-up model to analyze the energy consumption of three main departments in a five-star hotel, including Guestrooms, Food and Beverage Services, and Laundry. The electricity consumption prediction model for guestrooms consists of an electricity consumption evaluation for room lighting, corridor lighting, room air conditioning, and other powered devices within the guestrooms. The model is shown to be highly accurate. The natural gas consumption prediction model for F&B services is based on the number of food covers while the energy consumption prediction model for laundry is based on the laundry load. Both models focus on the demand side and can reasonably predict energy consumption levels. The bottom-up model provides a quick and effective way to assess the energy consumption of the main departments in a five-star hotel, thereby determining energy-saving potential and informing energy conservation management. Due to the limited amount of data, further research is required to improve these models and to identify additional energy saving measures.

Acknowledgements

This work was partially supported by Green Building Center of Tsinghua-Evergrande Research Institute.

References

Becken S, Frampton C, Simmons D (2001). Energy consumption patterns in the accommodation sector - the New Zealand case [J]. Ecological Economics, 39(3): 371-386.

Bohdanowicz P, Martinac I (2007). Determinants and benchmarking of resource consumption in hotels - case study of Hilton International and Scandic in Europe [J]. Energy and Buildings, 39(1): 82-95.

Building energy conservation research center (2011). 2011 Annual Report on China Building Energy Efficiency [D]. Beijing, China Architecture & Building Press, 2011, 273-275.

Building energy conservation research center (2016). 2016 Annual Report on China Building Energy Efficiency [D]. Beijing, China Architecture & Building Press, 2016, 235-240.

Chan W W, Lam J C (2002). Prediction of pollutant emission through electricity consumption by the hotel industry in Hong Kong [J]. International Journal of Hospitality Management, 21(4): 381-391.

Deng S M, Burnett J (2000). A study of energy performance of hotel buildings in Hong Kong [J]. Energy and Buildings, 31(1): 7-12.

Deng S M, Burnett J (2002A). Energy use and management in hotels in Hong Kong [J]. International Journal of Hospitality Management, 21(4): 371-380.

Deng S M, Burnett J (2002B). Water use in hotels in Hong Kong [J]. International Journal of Hospitality Management, 21(1): 57-66.

Deng S M (2003). Energy and water uses and their performance explanatory indicators in hotels in Hong Kong [J]. Energy and Buildings, 35(8): 775-784.

Farrou I, Kolokotroni M, Santamouris M (2012). A method for energy classification of hotels: A case study of Greece [J]. Energy and Buildings, 55: 553-562.

Gao X, Zhang D G, … Yang F L. (2007). Analysis of full-process energy consumption of Hotels' food and beverage services in China [J]. Building Science, 2007, 04:40-44+69 (in Chinese).

Hui S C M, Wong M K F (2010). Benchmarking the energy performance of hotel buildings in Hong Kong [C]. Proceedings of the Liaoning (Dalian)-Hong Kong Joint Symposium 2010, 2-3 July 2010, Dalian, China. Organizer of the Joint Symposium, 2010: 56-69. (in Chinese)

Jiang Y, Yang X. Electricity Equivalent Method in Energy Conversion and Evaluation [J]. Energy of China, 2010, 32(5): 5-11. (in Chinese)

Lai H D (2010). A study on high-star hotel guestrooms design in Guangdong, China [D]. South China University of Technology (in Chinese).

Lin C Y (2013). Boiler utilization and energy-saving cases for large-scale public building in Shanghai [J]. Journal of HV&AC, 2013 (11): 16-19 (in Chinese).

National Tourism Administration (2014). National Bureau of Statistics of Star-rated Hotels [Z]. http://www.cnta.gov.cn/html/2014-12/2014-12-23-%7B@hur%7D-11-52310.html

Önüt S, Soner S (2006). Energy efficiency assessment for the Antalya Region hotels in Turkey [J]. Energy and Buildings, 38(8): 964-971.

Priyadarsini R, Xuchao W, Eang L S (2009). A study on energy performance of hotel buildings in Singapore [J]. Energy and Buildings, 41(12): 1319-1324.

Rosselló-Batle B, Moià A, … Martínez V. (2010). Energy use, CO2 emissions and waste throughout the life cycle of a sample of hotels in the Balearic Islands [J]. Energy and Buildings, 42(4): 547-558.

Santamouris M, Balaras C A, … Gagliaa A. (1996). Energy conservation and retrofitting potential in Hellenic hotels [J]. Energy and Buildings, 24(1): 65-75.

Shen W D, Zheng P Z, Jiang D A (1979). Engineering thermodynamics [M]. People's Education Press, Beijing, China (in Chinese).

Shen X (2012). A study on five-star hotel guestrooms design in Beijing, China [D]. North China University of Technology (in Chinese).

Trung D N, Kumar S (2005). Resource use and waste management in Vietnam hotel industry [J]. Journal of Cleaner Production, 13(2): 109-116.

Wang J C (2012). A study on the energy performance of hotel buildings in Taiwan [J]. Energy and Buildings, 49: 268-275.

Wei Z (2011). Research on the Benchmark Tool of Public Building Energy Consumption [D]. China Academy of Building Research (in Chinese).

Xin Y, Lu S, … Wu W. (2012). Energy consumption quota of four and five-star luxury hotel buildings in

Hainan province, China [J]. Energy and Buildings, 45: 250-256.

Ye J Y (2013). Elaborate energy-saving design of smart hotel guestrooms [J]. Intelligent Building, 4: 039.

Zhang X Q, Li W (2010). Research and strategies of devices utilization in high-star hotel guestrooms [J]. Intemet Fortune, 3: 158-159 (in Chinese).

Zmeureanu R G, Hanna Z A, … Silverio (1994). Energy performance of hotels in Ottawa [J]. ASHRAE Transactions, 100(1): 314-322.