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RESEARCH ARTICLES

DEVELOPING AN ENERGY BENCHMARKING SYSTEM FOR HOTEL BUILDINGS USING THE STATISTICAL METHOD AND THE SIMULATION-BASED APPROACH

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ABSTRACT

Due to increased tourist activity, many cities now have a large number of hotel buildings. It is necessary to establish measures to evaluate energy use intensity to effectively manage energy consumption in this sector. This study uses a combined strategy to establish an energy benchmark for hotel buildings in Vietnam. First, a survey and analysis of actual building stock data of 50 hotels in Danang, Vietnam, was conducted. The survey-based benchmark and its related data was then used to build a reference energy model to estimate an energy benchmark for other climatic regions in Vietnam by using the energy simulation method. The results reveal that the average energy use intensity for hotels in Danang was 87.4 kWh/m^2.year or 8628.6 kWh/guestroom.year. However, this study proposes that because of the differing expectations of comfort standards, hotels of different grades should have separate benchmarks. This study also proposes an energy intensity-based rating scale, including 7 grades from the least energy intensive (grade A) to the most energy intensive (grade G), which can be used to manage, label, or encourage sustainable energy use in hotel buildings. The relationship between the energy use intensity and the occupancy rate of the hotels was reported, compared, and explained. It was found that occupancy rate has no significant impact on the energy use intensity. From the survey result, some predictive models were developed to estimate annual energy consumption of hotel buildings based on their grades. The simulated benchmarks for other regions were also achieved. The results demonstrate many potential applications in the management, design and construction, and renovation of this building type.

KEYWORDS

energy benchmarking, hotel, energy use intensity, energy labeling, energy rating scale, simulation-based benchmarking

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1. INTRODUCTION

The evaluation and rating of energy performance is increasingly seen as an essential component in building energy management. A good rating system may help identify low performance buildings and opportunities for improving energy efficiency and cost savings. It also establishes a basis for energy management policies that can positively impact the public and private sectors. A good rating system can increase profits for building owners. In addition to saving on energy costs, owners can achieve special recognition through a range of voluntary or compulsory certification programs and increase building resale values and rental incomes (Olofsson et al. 2004). Rating procedures often include energy benchmarking, a defined rating scale, and an evaluation of building energy performance.

Building energy rating and benchmarking procedures are usually focused on energy-intensive building types or those which are very common, such as residential buildings. In this study, we focus on energy rating and benchmarking for hotel buildings. This is an energy intensive building type because of the various grades/luxury levels of hotels and their complex systems and services. Furthermore, the number of hotels is increasing quickly in many Vietnamese cities with high tourist volumes, such as Danang city. Research on hotel buildings presents a challenge due to many complex factors, including their diversity in sizes, energy and engineering systems, and operation modes.

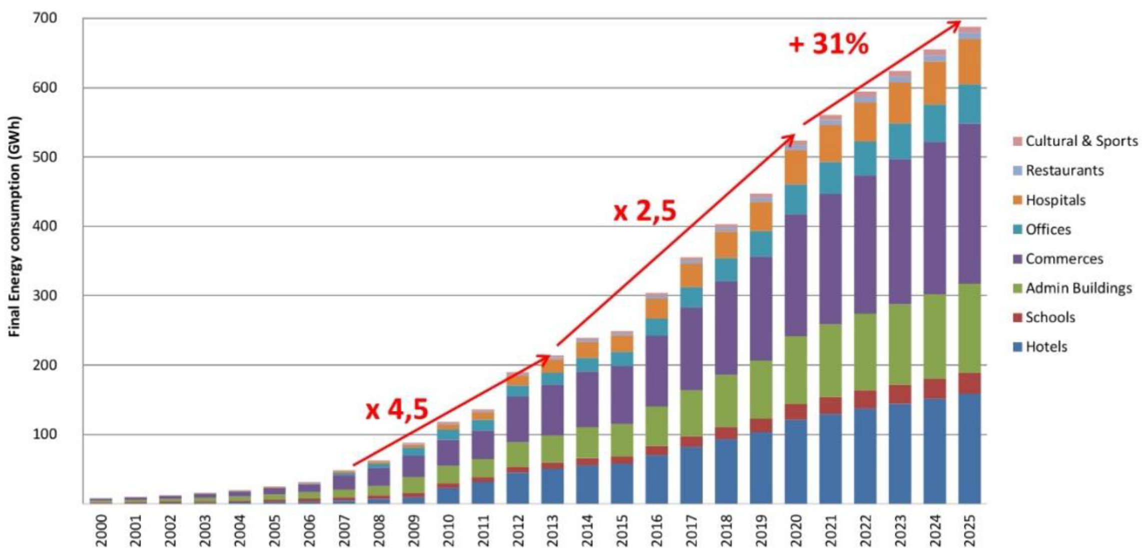
Danang is one the fastest growing cities in Southeast Asia and has recently experienced a rapid modernization process and economic boom fueled in large part by the tourist industry (Rockwood and Tran 2016). The number of hotels in Danang reached 600 in 2016 and continues to increase with an annual rate of 10%–14% (Thanh 2017). According to Vietnam Electricity (EVN), hotels had a total electricity consumption of 51 GWh in 2013, representing nearly 25% of electrical consumption in the tertiary sector. The average annual electrical consumption of a hotel building was 140,000 kWh/year in 2013. Air conditioning accounts for nearly 50% of the total energy consumption, regardless the type or grade of hotel (EVN 2013). This increasing trend is expected to continue in the coming years (see Figure 1). The local authority is trying to orient Danang towards a sustainable city according to which policies related to building energy efficiency become a focus of attention (Directive No. 08/CT-UBND in 15/9/2017). However, a scientific basis for this objective is still insufficient and inconsistent. In a broader perspective, Vietnam has just declared benchmarks for only a few industrial sectors in 2016. Benchmarks for other building types are still under development.

The main objective of this study was to develop an energy benchmark for hotel buildings in Danang and Vietnam, and a building energy use rating tool. Results of the study provide information that can support the improved design, construction and effective energy management of hotel buildings.

2. A BRIEF LITERATURE REVIEW

The energy performance of a building is usually measured by comparing its performance with that of a collected sample of other similar buildings (normally the same building type or category). The comparison is usually done using a performance benchmark which is calculated or estimated from the collected sample. Alternatively, an energy benchmark can be derived from a reference building model. An energy benchmark is often demonstrated by a normalized energy consumption index such as Energy Use Intensity (EUI), commonly measured in kWh/m^2/year, MJ/m^2/year, ton CO_2/m^2/year, or a similar metric. In some comprehensive

FIGURE 1. The present and projected trend of electricity consumption in the service sector of Danang (source: DaCliMB project 2014).



benchmarking studies, the percentage of each end use energy can be provided along with the total consumption.

Energy benchmarking of buildings has increased in scope and significance in many countries since the 1990s. Along with energy benchmarking, energy efficiency ratings have been developed and applied to buildings in specific categories. The term "Energy rating" is related to EU directive 2002/91/EC which mandates in some European countries that energy use data must be disclosed as part of the Energy Performance Certificate when a building is sold. Several big cities in the world also report annual energy consumption by sectors and building types as a basis for more efficient management practices. For example, the city of Seattle regularly publishes energy consumption benchmarks for the most important building types (Office of Sustainability and Environment 2015). Similarly, 26 other U.S. cities have adopted energy benchmarking and rating policies for public, commercial, and multifamily buildings (Palmer and Walls 2017).

The importance of energy benchmarking and rating of buildings has been the focus of much research. Chung *et al.* (2006) conducted a study on an energy benchmark for commercial buildings in Hong Kong. They used the multi-variable regression method combined with normalization to consider the deviation of energy consumption of buildings under different boundary conditions. Their results indicated that for supermarkets in Hong Kong, the average EUI is about 5852.6 MJ/m2.year with a standard deviation of 2591.2 MJ/m2.year. Hernandez *et al.* (2008) studied an energy benchmark and a building classification tool for non-residential buildings in Ireland by means of the mathematical method. They classified school buildings as classes A, B, C, D, E, F, and G, according to the energy efficiency level. Although the target buildings are schools, their developed classification system offered a valuable approach that was modified and applied in our study. The simulation-based method was also used in 2007; Mui *et al.* (2007) established an energy benchmark for ventilation systems in Hong Kong office buildings. Using the simulation method based on a series of governing equations, the authors established a cumulative distribution curve from which the annual energy consumption of the ventilation system was derived. They stated that the EUI of the ventilation system in office buildings is 674 kWh/m2.year with a standard deviation of 0.47 kWh/m2.year. Grolinger *et al.* (2018) developed a novel, statistics-based benchmarking approach that considers time slices of building energy consumption. By doing so, they were able to analyze different time periods of a building's operation and discover new opportunities for improvement and cost reduction. This approach of benchmarking scientifically sounds interesting if detailed consumption data (i.e. hourly consumption) can be determined which is not feasible in Vietnam.

The hotel industry is beginning to implement green design and construction practices, saving energy, water, and resources and thus helping to preserve the environment. Green building practices can provide healthy and comfortable indoor environments to hotel occupants including guests and employees (Ahn & Pearce 2013). Some studies have been done on benchmarking hotel buildings. Wu *et al.* (2010) built an energy benchmark from a collected sample of 29 3-star to 5-star hotels in Singapore using a simple regression method. The average EUI of these hotels was established around 427 kWh/m2.year. No benchmark corresponding to the hotel grades was mentioned. In a similar study conducted in Hong Kong by Deng and Burnett (2000), the authors collected energy data from 16 3-star to 5-star hotels. Although this sample was too small to return a reliable result, an energy benchmark of 564 kWh/m2.year was established. Zmeureanu *et al.* (1994) investigated the energy performance of 19 hotels in Ottawa among a total of 44. The average EUI was found to be 688.7 kWh/m2.year. The contribution of energy sources is also different: electricity accounts for 28.9%, gas 26.4% and hot steam 44.7%. In addition, the authors attempted to distinguish between weather-dependent and weather-independent variables as contributors to total energy use by using the normalization method PRISM. The above-mentioned studies had a weakness that failed to explain the relationship between the energy use intensity of a hotel and its grades, i.e. a 5-star hotel obviously consumes more energy than its 2-star counterpart. Review studies on hotel energy benchmarking also failed to indicate this weakness. Chan (2012) gave a review on developments and challenges of benchmarking methods and only listed several benchmarking results for hotels in many regions of the world regardless of their grades.

Teng *et al.* (2017) proposed using the optimization method to establish multivariable energy benchmarking models for budget hotels in China if survey data is not sufficient. Their calculated benchmarks were close to actual data, which was about 92.4 kWh/m^2.year. This study develops an analysis of energy benchmarks based on the simulation-based approach, which becomes the primary research method in this study.

Some scholars have conducted reviews on the methods for building energy benchmarking and rating, such as Chung (Chung 2011), Li *et al.* (2014) and Liddiard *et al.* (2008). Such studies provide an overview of the methods and works that have made prominent contributions to the literature. The reviews also mention some potential issues related to energy benchmarking that the present study should avoid, such as the following (Liddiard et al. 2008):

- Calculations are based upon small or/and unrepresentative samples;
- Methods may apply the normalization process differently, resulting in variation;
- Source data is often not reported in detail;
- Surveys only take "snapshot" data instead of long-term monitoring;
- Inconsistent interpretation of technical terms in the questionnaire, leading to incorrect collected data;

- Some methods appear to omit occupant-related factors;
- Survey procedures may lead to measurement of different features.

Several energy benchmarking methods for hotel buildings have been developed (Chung et al. 2006; Office of Sustainability and Environment 2015); however, these have been found to have certain limitations (Ballarini and Corrado 2009; Hernandez et al. 2008; Tronchin and Fabbri 2008). In response, this study uses a framework that helps to establish an energy benchmark for hotel buildings using a combined strategy, including a survey on the present hotel building stock and the development of a reference energy model.

3. RESEARCH METHODOLOGY

From the literature, several basic types of benchmarking methods have been found of which the most common have been identified as (Liddiard et al. 2008):

- Statistical models: based on a collected sample of building data, exploiting results from the distribution models, using medians and percentiles;
- Regression models: models derived from a two-variable or multivariate regression, combined with standard errors of regression;
- Mathematical models: calculation of the arithmetic mean or median of a sample, with or without normalization;
- Simulation-based approach: Using a building energy model (prototypical model), running on an energy simulation program;
- Hybrid models: combining two or more methods to obtain higher accuracy of the benchmark, such as: Stochastic Frontier Analysis (SFA), Data Envelopment Analysis (DEA), Intelligent clustering algorithm;
- Expert knowledge approach: information from many sources is gathered into a data set for deeper studies on the level of energy use as well as for relative energy efficiency.

A method may not include the occupant-related factors and/or building/energy cost and/or a normalization process. Other methods may result in different kinds of benchmarking indicators (Olofsson et al. 2004). Some studies used intelligent clustering algorithms to classify buildings based on their features instead of using building types (Santamouris et al. 2007; Gao and Malkawi 2014). It can be said that there is no single correct or incorrect method, but it is important to understand the relative impact of each strategy on benchmarking results.

In our study, the statistical method and a simulation-based approach were combined into a two-step process to achieve the benchmarks and rating tool. In the first step, a large sample of hotel energy consumption from the existing building stock of Danang was gathered. In the second step, data collected from the first step was used to establish a reference energy model from which energy benchmarks for other regions in Vietnam were developed. This strategy allows us to estimate a series of energy benchmarks throughout the country without the need of repeating a time-consuming survey in each location.

Most rating programs have been rather small, collecting data of less than one percent of the building stock (Olofsson et al. 2004). To increase statistical reliability, a survey of about 10% of the total number of hotel buildings in Danang, from 50–60 hotels was conducted. Investigated data includes basic information as follows:

- Monthly energy consumption, monitored in 12 continuous months of a year;
- Building sizes: floor area, volume, number of guestrooms and floor levels;
- Year built, renovation;
- Energy use systems including HVAC, domestic hot water, and lighting;
- Occupancy rate.

The survey was done by mail or by conducting the survey at building locations by the authors. To ensure the quality of the sample, criteria for choosing hotels were defined as shown in the priority list as follows:

- Hotel grade: hotels of all grades were included in the sample;
- Building location: the sample included hotels in all urban districts of the city;
- Building size: small (under 2500 m^2), medium and large buildings, low-rise and high-rise buildings were included.

The survey was conducted over the course of one year and data was collected from 55 hotels in Danang. During the screening process, the data of 5 hotel buildings did not meet the requirements of quality (e.g., abnormal consumption data, unclear information, unsuitable building occupancy) and these were removed from the sample. Key information from the 50 remaining hotels and the number of hotels of each class are briefly reported in Table 1. The complete dataset generated by the current study is available from the corresponding authors upon request.

TABLE 1. Summary statistics of the sampled hotels categorized by hotel grades.

		1-star	2-star	3-star	4-star	5-star
Number of buildings		10	6	21	8	5
Total floor area (m^2)	Min max	346 1155	537 2030	823 8368	2477 22790	28494 114970
	Mean	708	1294	3762	14673	77403
	Standard deviation	255	743	2116	8609	37277
Annual total energy consumption (kWh)	Min max	17919 98753	26015 132605	34594 885522	406114 3217875	2376075 22887529
	Mean	36413	75227	300999	1325203	12647491
	Standard deviation	23369	46146	209314	954043	9258015
Number of guestrooms	Mean	16.9	27.7	62.8	154.3	418.7
Occupancy rate	Mean	55.0	—	68.0	65.7	64.8
Building age (year)	Mean	11.0	10.4	7.2	4.3	8.3
Number of floors	Mean	4.9	5.9	9.7	15.4	23.0

The above survey results were screened, processed, and converted. Some missing values were interpolated by linear interpolations using their adjacent known values. The volume of diesel oil consumption of some large hotels was converted to an energy unit—kWh—using conversion coefficients recommended by Ireland's National Sustainable Energy Authority (2017). The LPG gas consumption was not included in the analysis as it was only used for cooking. The refined data was analyzed using Data Analysis and Statistical Software Stata v.10. The results of our analysis were carefully crosschecked with other survey data on benchmarking of hotels in Danang (Sơn 2016) and in other Vietnamese cities (USAID Vietnam Clean Energy Program 2016) to avoid illogical results.

4. RESULTS OF THE STUDY

4.1 Energy benchmark for each hotel class and all classes

An energy benchmark is usually developed by calculating the mean value of the normalized consumption of a sample set, i.e., the energy use intensity (EUI). However, in our case, different hotel grades have different energy use intensities, and the sample size of these hotel groups varies considerably. Therefore, the average energy use intensity was calculated using a special equation as follows:

$$\overline{EUI} = \frac{\sum_{i-1}^{5} EUI_{i\text{-star}}}{5} \tag{1}$$

where:

$\overline{EUI}$ is the mean normalized energy use intensity of generic hotel buildings;

$EUI_{\text{i-star}}$ is the mean energy use intensity of the sample set of the i-star hotels.

It was decided not to perform weather normalization for Danang because the survey area is quite small, within a city which has uniform weather conditions. Furthermore, most energy consumption data was collected from the 12 months of 2015. Lastly, widely used weather normalization approaches, such as the degree-day method, are likely not reliable if applied to cooling dominated climates (Wu et al. 2010). However, the normalization was included in energy benchmarking for other regions of Vietnam using the simulation-based method shown in section 4.5. The calculated energy use intensities (EUIs) of different classes of hotel buildings are shown in Figure 2. A generic hotel building in Danang consumes about 87.4 kWh/m^2.year or 8628.6 kWh/guestroom.year. The value of 87.4 is quite similar to that of 3-star budget hotels in China (92.4 kWh/m^2.year) (Teng et al. 2017) but compared with the energy benchmarks of hotels in Seattle (Office of Sustainability and Environment 2015) and Hong Kong (Deng and Burnett 2000), the EUI of hotels in Danang is much lower (87.4 versus 271 and 564 kWh/m^2.year, respectively). It is worth noting that the study in Hong Kong only had 16 hotels, three are 3-star, four are 4-star and nine are 5-star. Figure 2 also indicates that energy use intensity increases proportionally with the grade of the hotel, and the average EUI of 5-star hotels is nearly three times higher than that of 1-star or 2-star hotels. Figure 3 shows a similar trend reported in Figure 2, but with a larger difference between the luxury grades of hotels. The big gap between the 5-star hotels and others reveals that the guestrooms in these luxury buildings are possibly accompanied with many energy-intensive services and systems.

FIGURE 2. Mean Energy use intensity normalized by the total floor area.

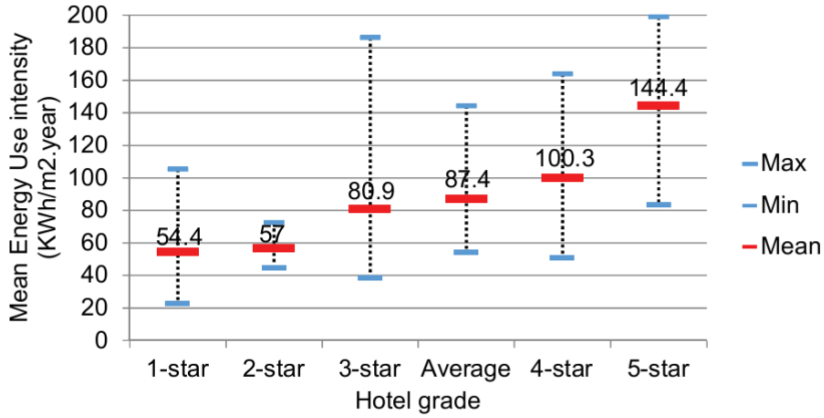
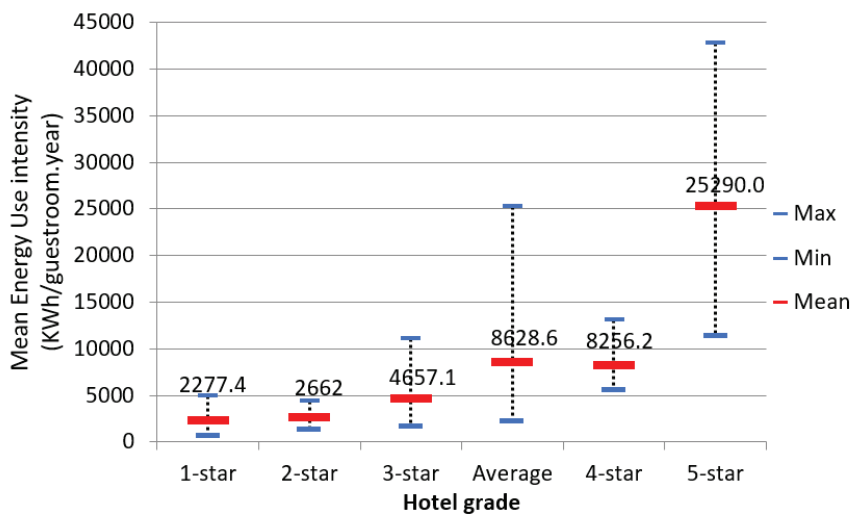


FIGURE 3. Mean Energy use intensity normalized by the number of guestrooms.



4.2 Develop an operational rating scale based on energy use intensity

There exist several rating techniques that can be used for rating building energy efficiency. Based on a collected sample, a rating scale can be derived by dividing the sample into some equal steps, or some equal frequency steps, or by using fuzzy clustering grading techniques (Santamouris et al. 2007). The rating method used for this case study follows the guide set out in the standard prEN15217:2005 (CEN 2005) and is described in Table 2.

This rating strategy is likely less sensitive to the variation of energy consumption by different regions as it is only reliant on the distribution frequency of the sample, hence being suitable for energy rating applications in all regions of Vietnam. This rating method has been applied in some international studies, for example (Hernandez et al. 2008; Burke et al. 2005). Figure 4 presents the actual cumulative frequency distribution of the energy consumption of the 50 hotels in the survey.

TABLE 2. Rating scale based on the guide in prEN15217:2005 (where R_{Bcode} is the threshold of EUI complied with the National building code; R_{bs} is the average EUI of the existing building stock).

	prEN15217:2005
Grade A	EUI < 0.5*R_{Bcode}
Grade B	0.5*R_{Bcode} ≤ EUI < R_{Bcode}
Grade C	R_{Bcode} ≤ EUI < 0.5*(R_{Bcode} + R_{bs})
Grade D	0.5*(R_{Bcode} + R_{bs}) ≤ EUI < R_{bs}
Grade E	R_{ks} ≤ EUI < 1.25*R_{bs}
Grade F	1.25*R_{bs} ≤ EUI < 1.5*R_{bs}
Grade G	1.5*R_{bs} ≤ EUI

From the regression curve (R^2 = 0.99) in Figure 4, two important values could be derived:

- R_{bs} = 72 kWh/m^2.year: median EUI of the sample. This value is considered the reference EUI of the present building stock;
- R_{Bcode} = 50 kWh/m^2.year: upper limit of the top 25% of the sample, in terms of EUI. This value is considered the reference EUI of the hotels having complied with the national building energy code QCVN 09:2013 in Vietnam (Ministry of Construction (MOC) 2013).

Table 3 shows the resulting rating scale based on energy use intensity for hotel buildings in Danang. This result can be used to inform consumers, to encourage good energy use practices,

FIGURE 4. Actual cumulative frequency distribution of the energy use intensity of the survey hotels in Danang.

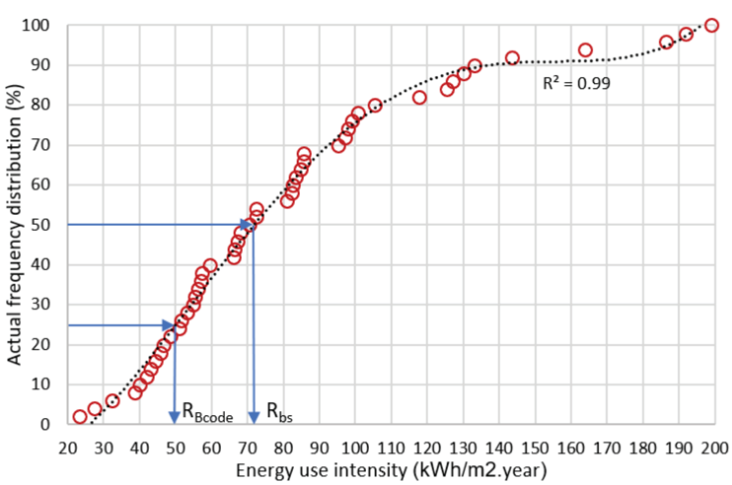


TABLE 3. The rating scale of the hotel buildings based on building energy performance.

Grade A	Grade B	Grade C	Grade D	Grade E	Grade F	Grade G
EUI < 25	25 ≤ EUI < 50	50 ≤ EUI < 61	61 ≤ EUI < 72	72 ≤ EUI < 90	90 ≤ EUI < 108	108 ≤ EUI

and to regulate or label consumers in the city. For other building types, this kind of rating scale is very useful as a building owner may know how well his/her building performs compared with the best (i.e. grade A) and the worst (i.e. grade G). For hotel buildings, the EUI strongly depends on the hotel grade thus reducing the meaning of this rating scale. For example, it may not fair to say that a 2-star hotel with the EUI of 57.0 kWh/m^2.year (grade C) is more energy efficient than a 5-star one with the EUI of 144.4 kWh/m^2.year (grade G). Thus, instead of using this scale as an energy efficiency rating tool, it should be considered an energy intensity indicator of hotel buildings. An energy efficiency rating scale for hotels should be developed for each hotel grade (i.e. five hotel grades need five separate rating scales), using the same approach described in this section. This would require survey data of a large number of hotels of each grade, which was not achieved in this study.

4.3 Relationship between building EUI and other factors

The monthly average energy consumption of hotel buildings in Danang is shown in Figure 5, accompanied by the monthly average temperature of the city. The graph shows that consumption during the summer months (May to September) was nearly double that of the remaining months of the year. The consumption profile followed the change of monthly average temperature, revealing that cooling energy is likely the most important end use in hotel buildings in the hot and humid climate of Danang.

One important concern in energy benchmarking hotel buildings is to determine whether the EUI is influenced by the annual occupancy rate. A correlation analysis was done on the collected sample as shown in Figure 6. The low regression coefficient, low R^2 and high P-value

FIGURE 5. Monthly energy consumption profile in hotel buildings in Danang. Data derived from the 50 investigated hotels.

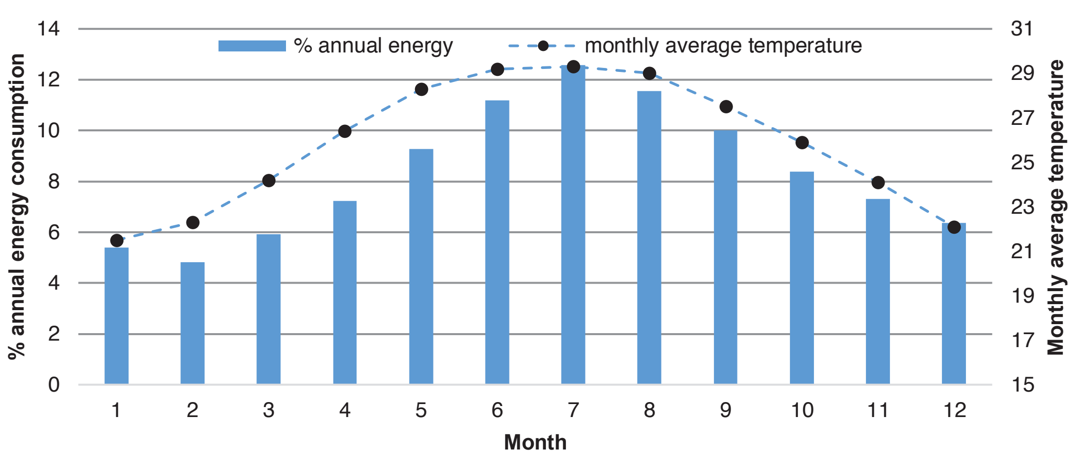
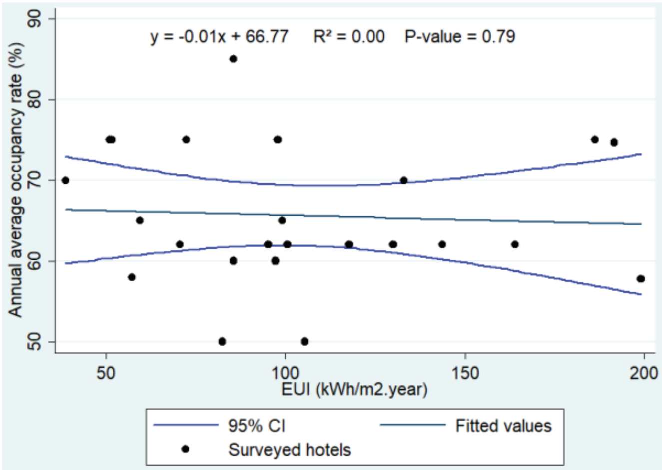


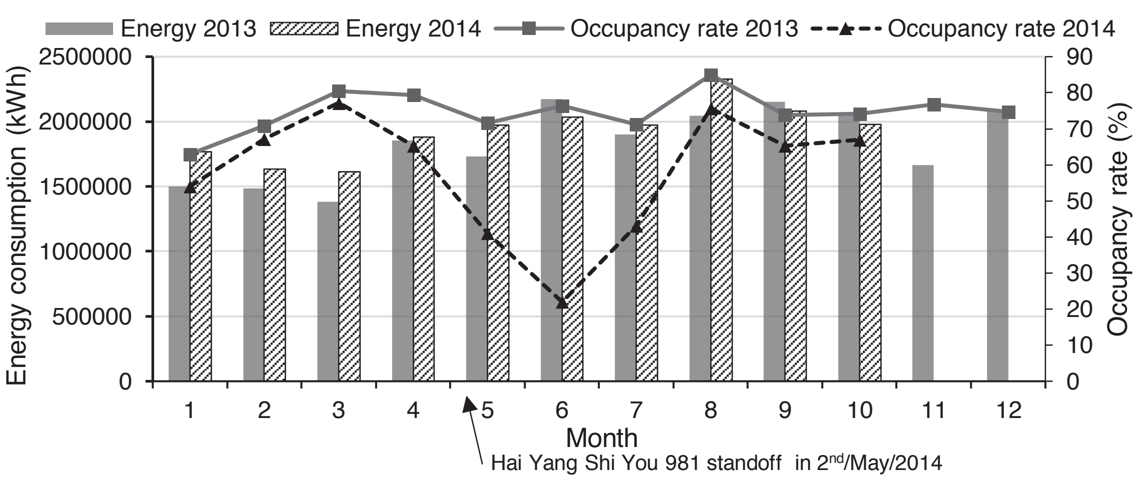
FIGURE 6. Correlation between EUI and the hotel average annual occupancy rate of the collected hotels in Danang.



(> 0.05) indicates that occupancy rate did not have any considerable affect on hotel energy consumption, and this correlation is not statistically significant. The weak correlation may appear unreasonable, but similar findings in hotel buildings in Hong Kong (Deng and Burnett 2000), Australia (Commonwealth of Australia 2002) and Singapore (Priyadarsini et al. 2009) have confirmed this. A deeper investigation in a large hotel X in Danang has been conducted. Energy consumption and occupancy rate of two consecutive years were compared as shown in Figure 7. From May to July 2014, the occupancy rate of hotel X dropped significantly due to the tensions between China and Vietnam arising from the Hai Yang Shi You 981 standoff. However, energy consumption of hotel X remained unchanged compared with the same period in 2013. This result, once again, supports the above finding.

The relationship between the EUI and the number of floors and the year of construction were also investigated, but the study did not find any considerable correlation. Many new hotel

FIGURE 7. Comparison of energy consumption of hotel X in 2013 and 2014 with the variation of monthly occupancy rates (lack of data of Nov and Dec 2014).



buildings even consume more energy than the older ones, although they were equipped with advanced systems and management strategies. Older buildings often use less energy because fewer appliances and services are provided inside, but newer buildings are better equipped (Olofsson et al. 2004). This indicates that only accounting for total energy consumption is insufficient to measure building energy efficiency. Evaluations of energy efficiency based on statistical surveys can be done, but they are vulnerable to easy misinterpretation.

4.4 Estimation of annual energy consumption in hotel buildings

In the building energy management field, it is sometimes neccessary to approximate the energy consumption of future buildings because it affects aspects in building planning, such as sustainable design strategies, cost and payback, and energy systems design. By performing the linear regression method on the survey data of the sample hotel buildings, this study developed simple predictive models that may be applied to forecast energy consumption of this building type. The models (correlation equations) are presented in Figures 8, 9 and 10, along with the 95% confidence interval (CI). The confidence intervals help users to identify reliable and less reliable areas of the models. The statistical significance of these models was tested by the chi-square (χ^2) test, which returned a P-value lower than 0.05 in all the models (all models were statistically significant). Hotels with grades from 1-star to 5-star can use the predictive models in Figure 8 or Figure 9 separately. Figure 10 shows the model which can be applied to all hotels (except 5-star hotels). As an example, assume that in the next 10 years there will be 100 new 3-star hotels built in Danang, with an average total floor area of 3762 m^2/hotel (according to the survey result). The predictive model in Figure 8 reveals that each 3-star hotel will consume about 300,964 kWh/year. As a result, Danang needs an increase of 30,096,406 kWh in energy supply (alternatively, a decrease of a similar amount in energy consumption) to meet the growth demand of hotel buildings.

4.5 Using the simulation-based approach to develop the energy benchmark for other regions

The simulation-based approach often establishes an energy benchmark via a reference building energy model (BEM). A reference BEM has many applications in energy benchmarking. A

FIGURE 8. Regression models applied to forecast annual energy consumption of 1-star, 2-star (on the left) and 3-star hotels (on the right).

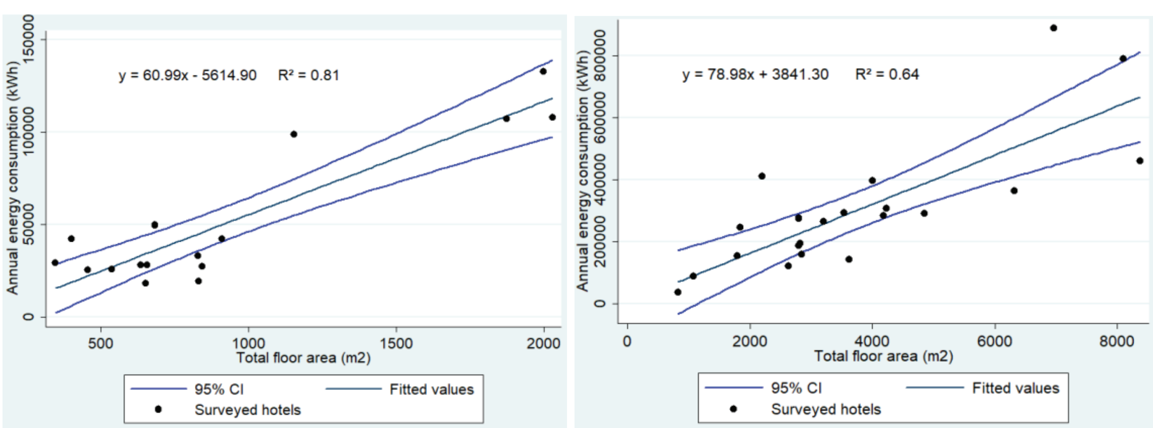
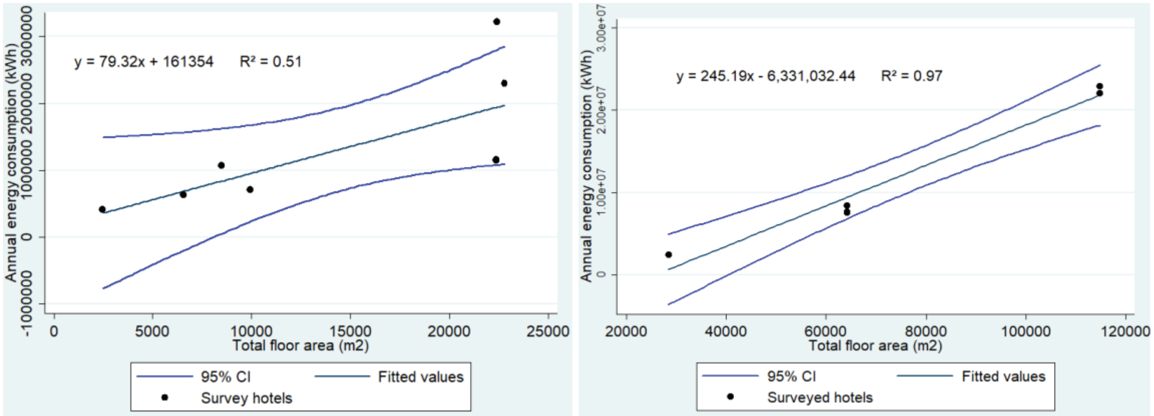


FIGURE 9. Regression models applied to forecast annual energy consumption of 4-star (on the left) and 5-star hotels (on the right).

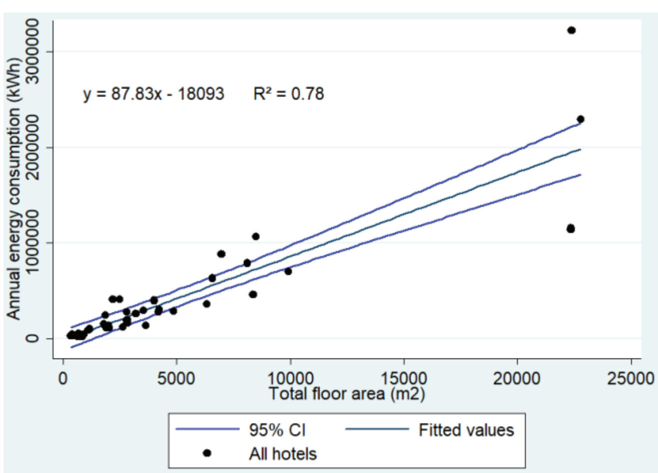


wide range of factors that contribute to variation in energy use can be analyzed and evaluated from the reference BEM. The model can also be placed in different climatic regions to see the effects of locations and climates on building energy consumption. A drawback of the approach is that the reference BEM may not be well calibrated to the actual building stock data (Sartor et al. 2000). To avoid this limitation, the present study applied several indicators derived from the survey building stock to examine the success of the calibration process. Consequently, the reference BEM of the study was carefully prepared.

4.5.1 Specifications of the reference BEM

In this study, the reference BEM represents a typical medium-sized hotel in Vietnam, which is developed from the Hampton Inn Prototype from Hilton Worldwide Holdings Inc. which also has hotels in Danang and Hanoi. The method used in the project "Achieving the 30% Goal:

FIGURE 10. Generic models applied to forecast annual energy consumption of all hotels (except 5-star hotels).



Energy and Cost Savings Analysis of ASHRAE Standard 90.1-2010" (Thornton et al. 2011) was adopted to develop the reference BEM. The process was implemented using a state-of-the-art energy simulation program—EnergyPlus (Crawley et al. 2001)—for the quantitative analysis.

The model is a 4-storey hotel, streching its long axis along the East-West direction. The air-conditioned area of the building is 3725 m^2, which corresponds to 92.8% of the net floor area (4014 m^2). The model has 67 thermal zones which represent all basic functions of a medium-sized hotel in Vietnam.

The building envelope parameters are similar to the type of requirements in the Vietnam building code QCVN 09/2013 (Ministry of Construction 2013), with an average window-to-wall ratio (WWR) of 10.9%. The WWR of the East and West facing facades is much lower, about 4%, while the remaining facades have an average WWR of 13%. The glazing areas of public spaces in the model used values for Low-E glass while transparent glass (no tint or coating) values were used for all hotel room windows.

All thermal zones (except storage rooms, staircases, and laundry rooms) were equipped with split-type air conditioners which have an average COP of 3.95 and are automatically sized to meet thermal loads in each zone. The heating setpoint was fixed at 20° C and the cooling set-point was adjusted to vary between 24° C and 27° C, depending on the function of each zone.

Air changes in the public spaces were controlled by a mechanical ventilation system. The hot water system was powered by electricity, supplying hot water to the guestrooms and the laundry service. Other appliances and systems, including elevators, pumps, lighting systems, sensors, and a building energy management system, were also reproduced in the model.

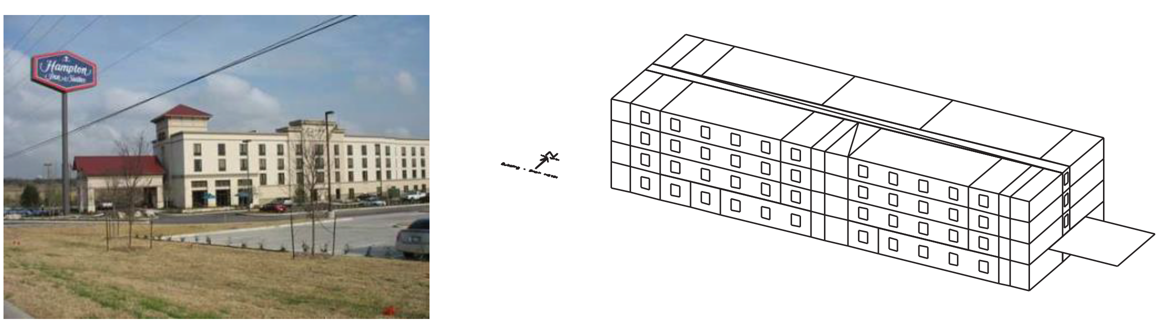
All functions incorporated in the model were powered by electricity from the grid and natural gas was only used for cooking in the hotel restaurant.

4.5.2 The calibration process of the reference BEM

In this study, the BEM was calibrated to confirm the correctness of the setting parameters and the goodness of fit between the model and the survey building stock data. The calibration was conducted by comparing the following indicators:

- The EUI of the BEM and the average EUI of the survey stock;
- Energy breakdown by end uses of the BEM and the survey stock;
- Monthly energy consumption profile of the BEM and the typical profile of the survey stock.

FIGURE 11. The 3D geometry of the reference BEM.

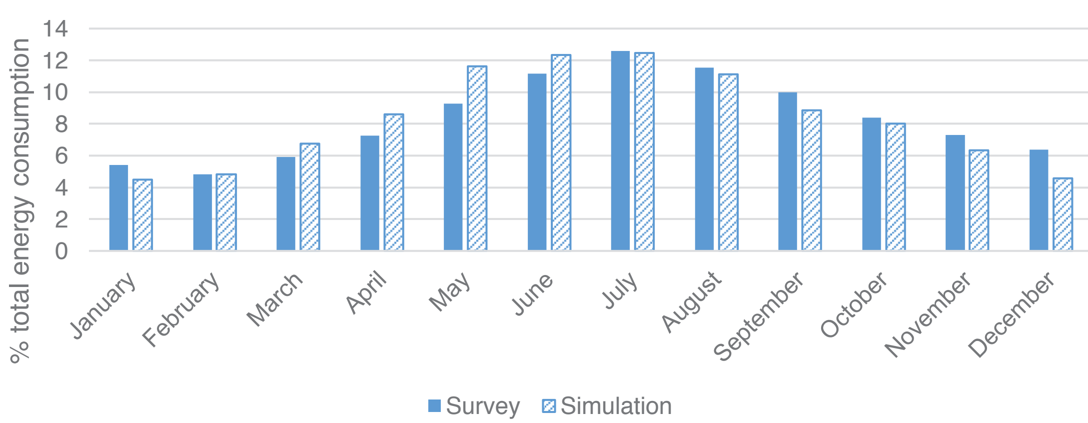


The final calibrated results of the BEM were compared with the data from the survey building stock as shown in Figure 12 and Table 4. The results indicate that there exist minor differences between these two data packs. The absolute error (Coefficient of variation of root mean square error—CV.RMSE) and the relative error (Normalized mean bias error—NMBE) between simulated and observed monthly energy consumption were only 12.34% and 0.00%, respectively. The correlation coefficient R^2 between the two data groups was 0.84. According to the guideline of ASHRAE (2002), monthly energy consumption of a calibrated energy BEM should achieve a CV.RMSE and a NMBE lower than 15% and 5%, respectively. In another document (ASHRAE 2009), ASHRAE stated that the R^2 between simulated and measured data should be larger than 0.75. These results and discussion have confirmed the goodness of fit of the BEM and the survey data. The calibrated BEM was able to reach an EUI of 87.6 kWh/m^2.year which is close to the average EUI – 87.4 kWh/m^2.year (a difference of only 0.2%).

TABLE 4. Energy consumption by end uses—comparison between simulated and survey data (Sơn 2016).

End use types	Simulated result (%)	Survey result (%)
Heating	0.00	0.00
Cooling	35.80	33.58
Lighting	15.23	13.36
Interior Equipment	15.77	15.40
Fans—Chiller	8.28	9.04
Pumps	0.02	0.03
Water Systems	24.90	28.59
Total End Uses	100%	100%
Total End Uses	87.6 kWh	87.4 kWh

FIGURE 12. Simulated monthly energy consumption and actual average consumption from survey data.



4.5.3 Energy benchmark for hotel buildings in other regions

We conducted a series of simulations on the calibrated BEM under different climatic conditions in Vietnam. To take the uncertainty of the model into consideration, at each region, 22 input parameters of the calibrated BEM were varied to imitate the variations of building design and operation under different conditions. The Latin hypercube sampling method (available in SimLab tool (Joint Research Centre–European Commission 2011)) was used to generate 240 simulation inputs, corresponding to 240 simulations per location. The parametric function of EnergyPlus was employed to run these simulations automatically (as being used in Nguyen 2013; Nguyen and Reiter 2015). The sample of 240 simulated EUIs was analyzed on Stata using a normal distribution curve. The EUI of the corresponding location was then identified by the center value achieved from the normal distribution curve (see an example of the curve in Figure 13). Figure 14 shows all simulated EUIs of key regions in Vietnam where a maximum difference of 20 kWh/m^2.year among these regions was obtained; the EUIs increase in the Southern regions and decrease in the Northern regions. We also found a similar study in the U.S. which shows that the EUI distribution of houses in the Northeast had its center at 62 kWh/m^2.year, Midwest and West at 59 kWh/m^2.year and the South at 58 kWh/m^2.year (Olofsson et al. 2004). The difference among regions were also minor.

For further reference, an energy model of a prototype of hotel buildings in the U.S. (Deru et al. 2011) was simulated under the climate of Miami, FL. which is hot and humid like Danang. The simulated EUIs shown in Figure 14 exhibit a significant difference between the cases of Vietnam and the U.S. It was assumed that hotel buildings in the U.S. support higher comfort standards and are equipped with energy intensive systems and services, and thus they consume more energy.

5. DISCUSSION

Initially, we assumed that hotel buildings may have a generic energy benchmark, regardless of hotel grades and other factors, as indicated in some studies (Chung et al. 2006; Deng and Burnett 2000; Priyadarsini et al. 2009; Wu et al. 2010). However, the results of this study showed that the EUI increases proportionally with the hotel grade (star-ranking) and the difference among the grades were significant. We therefore recommend that the energy benchmark

FIGURE 13. Distribution of the 240 simulated EUIs of the calibrated BEM, located in Ho Chi Minh city.

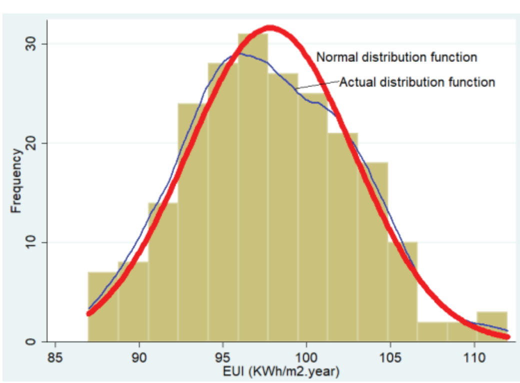
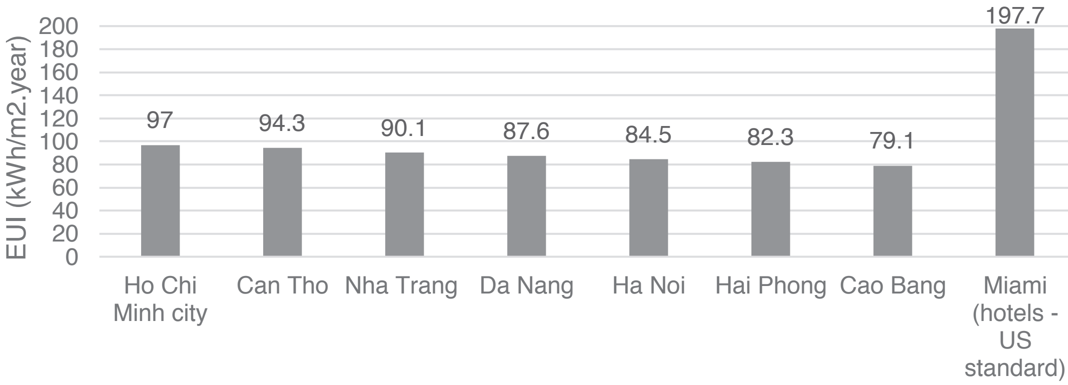


FIGURE 14. The EUIs of hotel buildings of some regions in Vietnam compared with that in Miami–USA.



for each hotel grade should be established separately. The 4-star and 5-star hotels have high EUIs and thereby represent an enormous potential for energy savings.

In the present study, the survey results indicated that some 5-star hotels in Danang had a high EUI, up to 200 kWh/m^2.year. This value is nearly equivalent to the EUI of 5-star hotels in Ha Noi and Ho Chi Minh city (218 and 221 kWh/m^2.year, respectively) (USAID Vietnam Clean Energy Program 2016). Different from other types of commercial buildings, hotels often provide many functions and services, including guestrooms, restaurants, swimming pools, retail shops, massage and spa services, and parking. Hotels often operate 24 hours a day, 7 days per week throughout the year. However, some functions (e.g., conference halls) may only be used a few times a year. The occupancy rate of a hotel may vary significantly in a year, but the central air handling system generally has to operate continuously to avoid concentration of odors and mold growth even in empty guestrooms and other spaces as well as to keep ductwork clean. These characteristics partly explain the weak correlation between the occupancy rate and the EUI of the survey hotels.

FIGURE 15. East and West facing glazing facades of hotel Y in Danang.

Among the survey hotels, some hotels had significantly higher EUIs than the average. For example, the 4-star hotel Y in Danang (Figure 15) had an EUI of 144 kWh/m^2.year while the average of 4-star hotels was only 100.3 kWh/m^2.year. As detailed energy end uses were not obtained, it is assumed that the large East and West facing unshaded glazed facades are not climate responsive and contributute to significant heat gain and intensive energy consumption. This case is a good reminder of the importance of climate responsive design in energy efficient buildings.

6. CONCLUSION

The paper presents a comprehensive study on energy benchmarking for hotel buildings in Danang and Vietnam using the survey data and the simulation-based approach. Analysis of the survey data of 50 hotels in Danang resulted in an average EUI of 87.4 kWh/m^2.year and 8628.6 kWh/guestroom.year. The study also proposes a separate energy benchmark for hotels of different grades as the EUI of each grade differs significantly from others.

A rating scale based on energy use intensity for hotel buildings was also proposed. It has 7 grades from A (least energy intensive buildings) to, B, C, E, F, G (most energy intensive buildings). The rating scale can be used to manage, encourage responsible energy use, or label more than 600 hotel buildings in Danang.

Other findings of the study include: i) monthly average consumption varies proportionally with monthly mean air temperature in Danang; ii) the independence of the EUI from the occupancy rate; iii) other factors that have minor impacts on the EUI of hotel buildings.

By using the simulation-based approach, a reference BEM was built under a stringent calibration process and was used to estimate benchmarks for other regions in Vietnam. Although the derived benchmarks were only an estimation, they can be used as a good energy reference for designers and managers. The simulated benchmark developed in this study promises to be useful if survey data in the region is not sufficient, or inconsistent, or where an energy benchmark is not well-established.

The results of this study would be more rigorous if the number of survey hotels in each grade, especially 5-star hotels, was larger. The results have many applications in energy management by city building authorities, hotel managers, and designers seeking energy efficient buildings. Overall, the methods promise to improve the energy efficiency of existing and future hotel buildings.

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