https://dx.doi.org/10.1016/j.enbuild.2022.112675

A comprehensive assessment approach to quantify the energy and economic performance of small-scale solar homestay hotel systems

Jianing Luo[1], Chaoqun Zhuang[2], Jianwei Liu[3,4]*, Kee-hung Lai[4]

[1] Department of Building Environment and Energy Engineering, The Hong Kong Polytechnic University, Kowloon, Hong Kong, China

[2] Data-centric Engineering, The Alan Turing Institute, London, United Kingdom

[3] School of Economics and Management, Dalian University of Technology, Dalian, China

[4] Department of Logistics and Maritime Studies, Faculty of Business, The Hong Kong Polytechnic University, Kowloon, Hong Kong, China

Abstract

In the tourism industry, hotels and homestay facilities account for considerable amounts of energy consumption and CO_2 emissions. Unlike other types of buildings, occupancy has significant fluctuations over time, while mostly being ignored or using a simple assumption based on energy use intensity or setting the occupancy level. Due to the lack of occupancy rate information, great uncertainties exist in hotel operations, which leads to erroneous estimates of energy consumption in existing hotel buildings. This paper considers hotel operation practices in China with the real occupancy rate data which is critical to reducing the uncertainty of energy consumption patterns. The study proposes a two-stage comprehensive and quantitative performance assessment approach for the homestay hotel building taking into account the system's energy and economic performance simultaneously. Regarding energy performance, there are two key facets to consider: renewable energy penetration and grid impact performance. Additionally, the economic performance (annual income and extra annual investment) of various energy portfolios is evaluated using break-even analysis. The impacts of large fluctuation in occupancy rate on electrical loads are considered and assessed in typical homestay hotels. The proposed assessment approach can comprehensively quantify the impacts of the photovoltaics (PV) areas and battery capacities on the system performance in terms of energy and economics. According to the results of the occupancy-based assessment, the ideal PV area and battery capacity are 400 m^2 and 16 kWh, respectively, as opposed to the optimal energy portfolios (PV area 600 m^2 and battery capacity 24 kWh) determined from conventional assessment results.

Keywords: solar homestay hotel, dynamic occupancy rate, break-even analysis, economic and energy performance, renewable energy penetration

* Corresponding authors: Jianwei Liu, jianweiliu@dlut.edu.cn;

Highlights

- A quantitative assessment approach of solar homestay hotels is proposed;
- The energy and economic potentials are quantified and analyzed comprehensively;
- Dynamic occupancy rate is adopted to increase the accuracy of the assessments;
- A new occupancy-based load profile is proposed and used in the assessments;
- Break-even analysis is adopted in the economic assessment;

1. Introduction

Adopting renewable energy practices is a topical issue for business operations since global climate changes have evolved as major public concerns in recent years. The leading sources of greenhouse gas savings that countries need to focus on in order to realize their commitments under the Paris Agreement are switching fuels to renewable energy and enhancing end-use energy efficiency, which is a key scientific problem that needs to be addressed urgently and has received a lot of attention from both academia and industry in [1, 2].

The economic consequences of climate change for regions where tourism and hospitality are important can be substantial [3]. Climate change already affects tourism and hospitality regionally, through diverse impacts on natural and cultural heritage and changes in demand patterns [4, 5]. As awareness of tourism and hospitality's energy impacts on global environments increases, and as knowledge of energy consumption's effects on sustainability grows of tourism and hospitality, so does the need for hotel operators to develop proactive energy management strategies [6]. However, the unique characteristics of energy consumption behaviour in hospitality industries (e.g., how to comprehensively and quantitatively assess the energy and economic potential for renewable energy adoption) make it difficult to assess the relative merits of various energy management options.

As for renewable energy adoption, there are growing low carbon requirements in tourism and hospitality markets, urging companies to undertake more responsibilities for relieving their caused environmental damages. Especially in hotel building energy consumption, huge potentials to increase renewable energy usage and decrease carbon emission are obvious [7]. Nevertheless, academia and industry are still dubious and hesitate about the financial value of adopting renewable energy practices (i.e., adopting solar power in this study) because of the additional cost incurred and the long payback period. In particular, it needs extra investment to comply with related standards (e.g., ISO 14000, environmental labelling) [8] and installation equipment (e.g., solar panels). The replacement of current practices with greener approaches also incurs financial commitment with uncertain payback due to the dynamic consumer demand.

Regarding one specific building type (homestay hotels), numerous studies were examined in the hotel renewable energy adoption sector by taking into account various techniques and features. Farrokhi et al. [9] evaluated the dynamic energy performance of the hotel system considering the integration of the power generation from solar radiation with hydrogen energy storage. Lamagna et al. [10] proposed a techno-economic assessment approach to quantify the hotel system energy performance under a special type of battery storage (i.e., reversible Solid Oxide Cell). Meschede et al. [11] and Beccali et al. [12] examined the impacts of the intermittent and random characteristics of the power generation from renewable sources on the energy performance of the hotel system.

In addition, the impacts of hotel energy consumption are also considered and investigated in hotel buildings. The fluctuations in consumer demand, as determined by the occupancy rate in this study, are mostly ignored, although they have a substantial impact on the energy and economic performance of the homestay hotel building systems [13-17]. For instance, with reference to Lagos, Nigeria, Oluseyi et al. [14] found that there was a significant correlation between energy consumption and total floor area, number of guest rooms, number of equivalent guest rooms, and number of employees. Luo et al. [15] proposed one assessment approach to quantify the hotel building reliability performance considering the impacts of the dynamic loads and inrush current caused by the load fluctuations based on the assumption of a full load ratio.

It can be observed that many studies have identified energy consumption patterns in the hotel sector by extracting features with various techniques, such as cluster analysis taking into account hotel size [18], building energy simulation taking into account the influence of atrium [19], long-range energy alternatives plan taking into account various renovation scenarios [16], and post-evaluation taking into account hotel retrofitting[13]. However, the real occupancy rate is particularly important in accessing energy efficiency and corresponding economic performance for the tourism and hospitality industry because of the significant fluctuations in consumer demand, which is rarely examined or solely uses a simple assumption [5].

In summary, there is currently a dearth of research regarding the assessment of energy consumption with the consideration of the occupancy rate. Due to the lack of occupancy rate information, great uncertainties exist in hotel operations, which leads to erroneous estimates of energy consumption in existing hotel buildings. Therefore, to bridge the gap, this study aims to develop a quantitative approach to assess the energy and economic performance of solar homestay hotels (SHH) concerning the dynamic daily occupancy rate. This quantitative assessment approach can be used not only in a single solar homestay hotel but also in one cluster of solar homestay hotels. The main novelties of the proposed assessment approach and original contributions of this study are as follows:

- A two-stage comprehensive performance assessment approach for the homestay hotel building is proposed considering the system's energy and economic performance simultaneously;
- Two major parameters (i.e., PV area and battery storage with their combinations) of solar homestay hotel systems are quantified in the evaluation of energy and economic performance;
- The comparison results between the occupancy-based supply-demand profile and the conventional supply-demand profile are presented and analyzed;

2. Quantitative assessment approach and procedure

2.1 Outline of the quantitative assessment approach

Fig. 1 depicts the procedure of the quantitative assessment for the solar homestay hotel in terms of energy performance and economic performance, involving two major stages. In the first stage, the supply-demand profile is calculated according to the features of the hotel buildings. In the second stage, the energy performance and economic performance are quantified and assessed according to the obtained supply-demand profile from the first stage. The details of these two stages are presented as follows,

- **First stage:** three types of input data (i.e., basic information of the solar homestay hotel building system, weather data, and specifications of the renewable power generation) are collected and used in the calculation of the supply-demand profile for these solar homestay hotels. The power generation is calculated according to the mathematical model in MATLAB and the power consumption is calculated according to the physical model in TRNSYS. Then, according to the hotel occupancy rate and the calculated load profile, the occupancy-based load profile is quantified and obtained. Compared with other types of buildings, fluctuations in the daily occupancy rate for hotel buildings are very significant because of many different influential factors (such as COVID-19, holidays, weather, and so on). To achieve an accurate supply-demand profile and then assess the energy-related and economic performance of proposed solar-powered systems, the real occupancy rate data is collected in this study.

- **Second stage:** the assessments of the system energy performance and economic performance are quantified and analyzed respectively. Two outputs (namely, grid impacts and the generation of renewable electricity) are taken into account for the energy performance assessments. The former focuses on the system performance in renewable power generation while the latter is concerned with the impacts of the PV areas and battery installations on the power grids. For the economic performance assessments, the system economics are quantified firstly concerning the overall costs of the system when the renewable power generation facilities are equipped. Then according to the quantified system economics, the income and extra investment are calculated and used in the break-even analysis. In the end, the electricity price is quantified.

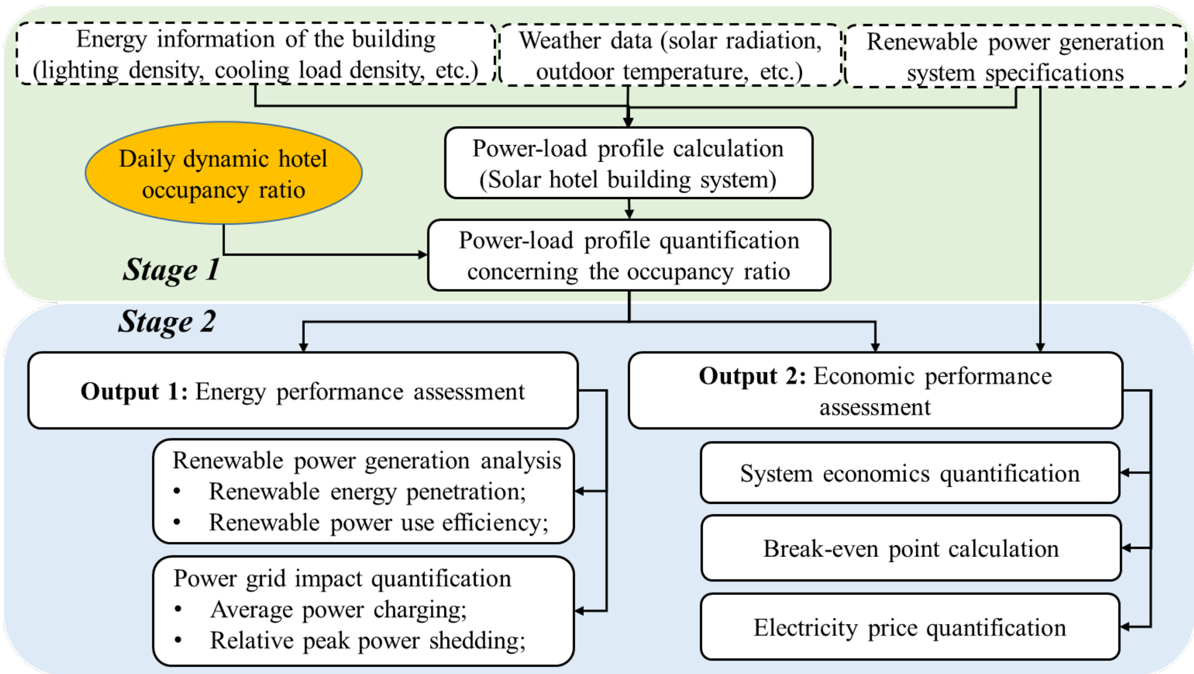


Fig. 1. The framework of the tech-economic quantitative assessment for the solar homestay hotels

2.2 Occupancy-based load profile quantification

In this study, a total of four homestay hotels are involved. The total load is the sum of these homestay hotel loads, as shown in Eq. (1). Loads of the homestay hotel (calculated by using Eq. (2)) consist of other electrical loads (e.g., lighting and plug loads) and the cooling load and as well as the coefficient of performance (COP). The cooling load and other electrical loads are calculated according to the occupancy rate of the hotel ($R_{ocp,n}^{D}$), cooling load and individual electrical load for the 100% occupancy rate, as shown in Eq. (3) and Eq. (4) respectively.

$$P_{tot}^{t} = \sum\nolimits_{n=1}^{N} P_{hotel,n}^{t} \tag{1}$$

$$P_{hotel}^{t} = P_{cool,hotel}^{t}/COP + P_{ot,hotel}^{t} \tag{2}$$

$$P_{ot,n}^{t} = \begin{cases} P_{ot,n}^{t} \times R_{ocp,n}^{D} & if \ R_{ocp,n}^{D} = 1 \\ 2 & if \ R_{ocp,n}^{D} = 0 \end{cases} \tag{3}$$

$$P_{cool,n}^{t} = \begin{cases} P_{cool,n}^{t} \times R_{ocp,n}^{D} & if \ R_{ocp,n}^{D} = 1 \\ 0 & if \ R_{ocp,n}^{D} = 0 \end{cases} \tag{4}$$

2.3 System energy performance assessment

2.3.1 Quantification of the renewable power generation

Two key indicators (renewable energy penetration and renewable power use efficiency) are selected to quantify the performance of renewable power generation. Renewable energy penetration (*REP*), as a key performance indicator, is used to quantify the ratio of the total used renewable power generation ($P_{ur,t}$) to the total electrical load (P_{tot}) as shown in Eq. (5). The ratio will be close to one if renewable energy generation can provide practically all of the demand.

$$REP = \sum\nolimits_{t=1}^{t=8760} P_{ur,t} \Big/ \sum\nolimits_{t=1}^{t=8760} P_{tot,t} \tag{5}$$

Renewable power use efficiency (RPUE) is a ratio of the total used renewable power generation ($P_{ur,t}$) to the total renewable power generation ($P_{ren,t}$), as shown in Eq. (6). RPUE measures the use efficiency of renewable power generation. It can effectively reflect the efficiency of renewable power generation use during the operation. The ratio will be close to one if demand is satisfied by practically entire renewable energy generation.

$$RPUE = \sum\nolimits_{t=1}^{t=8760} P_{ur,t} \Big/ \sum\nolimits_{t=1}^{t=8760} P_{ren,t} \tag{6}$$

2.3.2 Quantifications of the power grid impact indicators

The power grid impact indicators consist of the charging power and peak load shedding. The former measures the average hourly charging power and the latter shows the daily peak load shedding. The details of the calculation are presented as follows,

- **Charging power** is the value of the charging power from the main grids, which is calculated in Eq. (7). It is the main measure to address the issue of the power inadequate supply due to unpredictable and uncontrollable features of renewable power generation. The average charging power is considered and quantified in Eq. (8), where P_{cha}^{t} is charging power at the timestep *t* and $P_{cha,ave}$ is average charging power. P_{con}^{t} and P_{avi}^{t} are the power consumption and available power generation at the timestep *t*. The available power generation is determined by renewable power generation ($P_{ur,t}$) and battery discharging ($P_{bat,t}$), which is calculated in Eq. (9).

$$P_{cha}^{t} = P_{con}^{t} - P_{avi}^{t} \tag{7}$$

$$P_{cha,ave} = {}^{1}/_{T} \sum_{t=1}^{t=8760} (P_{con}^{t} - P_{avi}^{t}) \tag{8}$$

$$P_{avi}^{t} = P_{ur,t} + P_{bat,t} \tag{9}$$

- **Peak load shedding** refers to the ratio of the daily peak charging power (P_{peak}^{D}) with renewable power generation equipment to the daily peak charging power ($P_{peak,wo}^{D}$) without renewable power generation equipment as shown in Eq. (10) [20]. In addition, the average daily relative peak load shedding is calculated in Eq. (11) [21], where *D* is the total of the days, *d* is one day, R_{PLS}^{d} is peak load shedding per day and $R_{PLS,ave}$ is average daily peak load shedding.

$$R_{PLS}^{d} = (P_{peak,wo}^{d} - P_{peak}^{d})/P_{peak,wo}^{d} \tag{10}$$

$$R_{PLS,ave} = {}^{1}/_{D} \sum_{d=1}^{d=D} R_{PLS}^{d} \tag{11}$$

2.4 System economic performance model

2.4.1 Quantification of the system economics

The total cost is made up of three primary cost categories: the initial cost, the operating cost, and the maintenance cost. (Eq. (12)). The initial cost is the sum of the annual initial cost for all major electrical facilities in the solar homestay hotel system, as shown in Eq. (13), where, the $C_{fac,k}$

represents the initial cost of the *k*th microgrid facility and its subscript "*fac*" is the microgrid facility. Y_k represents the total years of its life cycle. The operation cost is computed by multiplying the total annual charging electricity and the real electricity price ($Pr_{ele,real}$), as shown in Eq. (14). The maintenance cost is the annual maintenance cost that investors have to pay per year to provide the maintenance for the major facilities of the system per year. It is 1% of the initial cost as shown in Eq. (15) based on [22].

$$C_{ov} = C_{ini} + C_{opt} + C_{man} \tag{12}$$

$$C_{ini} = \sum (C_{fac,k} \times 1/Y_k) \tag{13}$$

$$C_{opt} = (\sum_{t=1}^{8760} P_{grid}^{t} \times \Delta t) \times Pr_{ele} \tag{14}$$

$$C_{man} = 1\% \times \sum (C_{fac,k} \times 1/Y_k) \tag{15}$$

2.4.2 <u>Break-even analysis</u>

Break-even analysis (BEA), as a commonly used concept of financial analysis, refers to the sales amount that is required to cover total costs [23, 24]. The break-even point (BEP) is determined according to the income and extra investment as shown in Eq. (16) [25]. In this study, the income and the extra investments are the annual income and annual extra investment within a particular period (i.e., typical year). The annual income is the reduction of the operation cost as shown in Eq. (17), where $C_{opt,non}$ is the operation cost without installing PV panels and $C_{opt,solar}$ is the system operation cost with installing PV panels. The annual extra investment is the sum of the annual initial cost and annual maintenance cost of the renewable power generation system, calculated by Eq. (18).

$$BEP = f(C_{ic}, C_{ei}) \tag{16}$$

$$C_{ic} = C_{opt,non} - C_{opt,solar} \tag{17}$$

$$C_{ei} = \sum (C_{ini,k} + C_{man,k}) \tag{18}$$

2.4.3 <u>Levelized cost of energy calculation</u>

The equivalent levelized cost of energy ($C_{LCOE,equ}$) is directly to see the changes of the electricity price when renewable power generation is involved [26]. The equivalent calculation of LCOE can be computed considering the real LCOE ($C_{LCOE,real}$), the annual income and annual extra investment as well as the total load, as shown in Eq. (19).

$$C_{LCOE,equ} = C_{LCOE,real} - (C_{ic} - C_{ei})/E_{tot} \tag{19}$$

3. Model development of microgrid structure

3.1 Overview of the solar homestay hotels and their energy systems

Fig. 2 shows the basic configuration of the solar homestay hotel system that serves four homestay hotel buildings in typical tropical regions. Considering the properties of the building loads in tropical regions, the need for heating is negligible. The power consumption consists of cooling load and individual electrical load. The PV panels equipped with battery storage as the renewable power generation together with the main grids are selected to satisfy the power requirement of these homestay hotels. Due to the limitation of the government policy, renewable power generation from the PV panel cannot be sold to the utility grid. Electric chillers produce cooling to satisfy the thermal environment control requirement of buildings. Considering the limitations in reality, the area of the PV panel, ranging from 100 m^2 to 800 m^2, is used in this system.

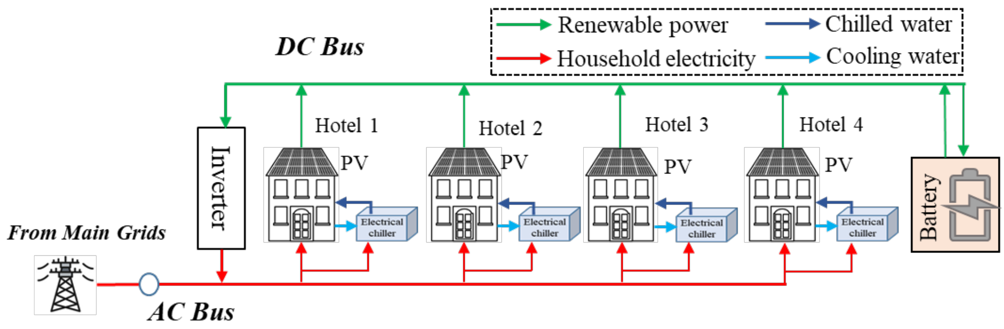


Fig. 2. Configuration of the solar homestay hotel system in a tropical region

As for these four homestay hotel buildings, they have almost similar parameters in terms of building envelopes. Each floor of these hotels has four windows facing in four different directions. The window ratio is about 0.3 in the south and 0.4 in other directions. They have 3 identical floors with dimensions of 15 m × 14 m and the ceiling height is 2.5 m. For the designed parameters of these hotel buildings, the designed equipment load density and lighting power density are 15 W/m^2 and 10 W/m^2, respectively [27]. The main parameters of the building energy system are listed in Table 1.

Table 1: Main parameters of the building energy system

Building energy information		
Dimmable lighting	Lighting density	10 W/m^2
Other electrical equipment	Equipment load density	15 W/m^2
Fresh air Ventilation	-	15 L/h×person^{-1}
Infiltration rate	-	0.2 air changes per hour
HVAC system parameters	Cooling load density	153 W/m^2
	Indoor air temperature	25 °C
	Relative humidity	50-60%

The considered four homestay hotels are located in Sanya, Hainan, where solar energy has a promising potential to provide a sustainable power supply. The annual solar radiation is shown in Fig. 3. The highest hourly solar radiation and average hourly solar radiation are 3.6 kWh/m^2 and 0.6 kWh/m^2, respectively.

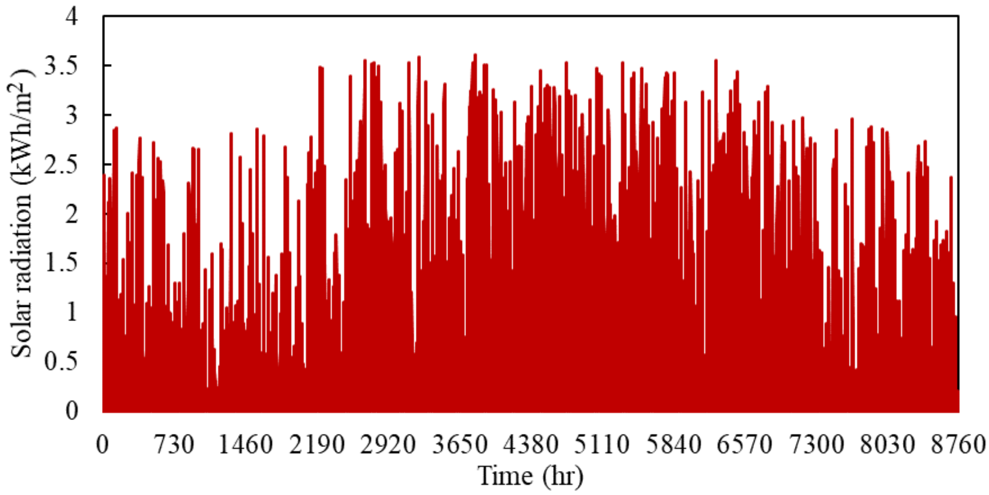


Fig. 3. Annual profile of the solar radiation in Sanya, Hainan

3.2 Battery storage capacity determination for the homestay hotel building energy system

Battery storage is regarded as an effective measure to smooth the power gap due to the intermittent nature of power generation from solar energy. It can provide the service to store surplus electricity from renewable power generation. In this study, the battery storage is connected to the DC bus by using a bidirectional buck-boost converter for charging or discharging. The range of the battery storage capacity is determined according to the maximum hourly power generation of solar energy under a given PV area. The maximum capacity of the battery storage is equal to the maximum hourly power generation. Table 2 shows the determined battery capacity ranges concerning the different PV areas.

Table 2: Determination of the battery capacity range concerning the different PV areas

PV area (m^2)	Maximum power generation (kW)	Battery capacity range (kWh)
100	20	[0,20]
200	40	[0,40]
300	60	[0,60]
400	80	[0,80]
500	100	[0,100]
600	120	[0,120]
700	140	[0,140]
800	160	[0,160]

3.3 Solar power generation model of the solar homestay hotel energy system

Renewable power generation from solar energy is used to provide a sustainable power supply and meet system demand. It acts as a major renewable power supply in this study. The power generation from solar energy is determined by the overall efficiency of PV panels (η_{pv}), dynamic solar radiation (*Rad*) and dynamic PV cell temperature, as well as the total area of PV panels (A_{PV}), which is calculated in Eq. (22) according to [28]. The overall efficiency of PV panels η_{PV} is set as 20% in this study [29]. The cell temperature of the PV panels is determined in Eq. (21) and T_{amb} represents the ambient temperature in this equation.

$$P_{PV} = Rad \times \ A_{PV} \ \times (1 + K_{PV}(T_{PV} - T_{ref})) \times \eta_{pv} \tag{20}$$

$$T_{PV} = T_{amb} + 0.0256 \times Rad \tag{21}$$

$$0 \leq P_{PV,t} \leq P_{PV}^{Max}, \forall t \in [1,8760] \tag{22}$$

3.4 Model development of the solar homestay hotel demand-side energy system

3.4.1 *Physical model development*

The demand-side physical model is developed to simulate the dynamic load of these four hotel buildings. The mentioned four hotel buildings are simulated through a model built in TRNSYS. The power consumption of buildings in typical tropical regions consists of the cooling load and other electrical loads (e.g., lighting and plug loads). The former is determined according to the weather data and cooling load density. The latter is determined according to the electrical load density and light density. Besides, the cooling load is not considered and other electrical loads are assumed as 2 kW, if there are no occupants. It is worth noticing that the coefficient of performance (COP) of the cooling plant is set as 4 to simplify the calculation [30].

3.4.2 Occupancy rate of the solar homestay hotels

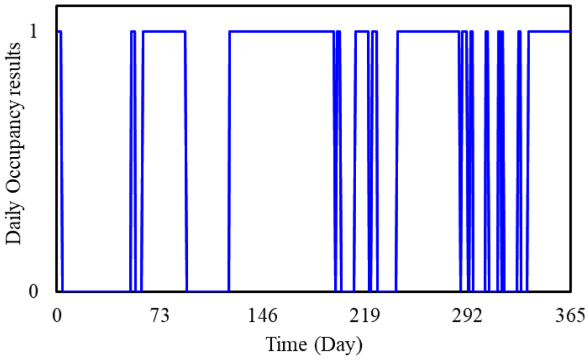
- **The importance of the occupancy rate for hotel energy performance**

  The occupancy rate, as one of the most uncertain sources, is a key factor to conduct the energy and economic prediction in the tourism and hospitality industry. Especially for the hotel buildings, it varies significantly over a year. However, the existing studies mostly quantify the impacts of occupancy rate on the energy performance by using the energy use intensity (EUI) [31] or setting the occupancy level [32] due to the data unavailability, which may lead to deviation of the energy performance and obtain the overestimated/underestimated assessment results. To fill this gap, we collected the occupancy rate data on vocational rental properties through a research company that provides data and analytics services about short-term rental markets in China and the United States whose service has been widely used and endorsed by leading industry clients in government and universities.

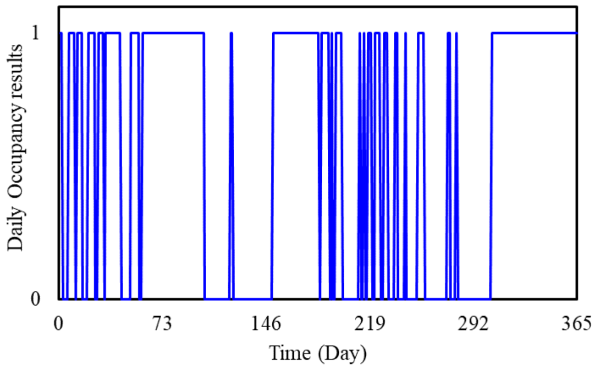
- **Data characteristics of homestay hotel occupancy**

  The data set we used contains a daily panel of all vocational rental properties in one of the most developed tourist cities in China, namely Sanya City, called "Oriental Hawaii", which is an international tourist city with tropical seaside scenery. Tourism is a pillar of Sanya's economic development, accounting for 70% of its total income [33]. And there is a large number of vocational rental properties entering and booming in this region (i.e., 4,693 properties totally during the observation period).

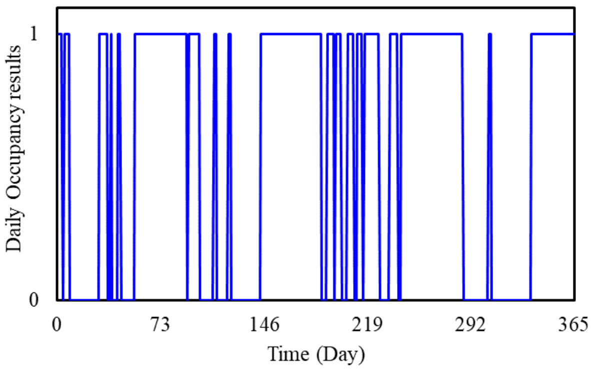
  Our observation period is from January 2018 and October 2019 (a total of 46 months) including four typical home-sharing properties, which is before the occurrence of COVID-19 (in December 2019). Thus, the selected four typical vocational rental properties from this coastal city are used to demonstrate our proposed energy and economic assessment approach. The statistical description of such four hotels is shown in Fig. 4. The occupancy rate is of great fluctuations with uncertainty.



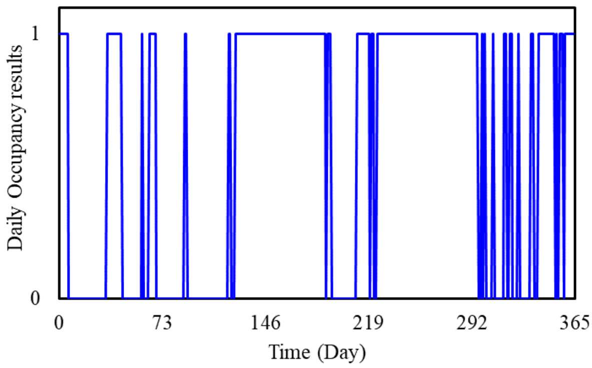
(Hotel 1)



(Hotel 1)



(Hotel 3)



(Hotel 4)

Fig. 4. Annual occupancy rate of such four homestay hotels

3.4.3 Battery storage and its working principle

To simplify the calculation, both the overall charge and discharge efficiencies are set as 0.85. To make the battery storage work with a safety range, the maximum charging rate ($R_{batch,max}$) and discharging rate ($R_{batdch,max}$) are set as 20% of the battery capacity and 50% of the battery capacity respectively, as shown in Eqs. (25) and (26) [34]. The minimum limit ($Cap_{bat,min}$) and maximum limit ($Cap_{bat,max}$) of the battery capacity are set as 20% and 80%, as shown in Eq. (27).

$$0 \leq R_{batch} \leq R_{batch,max} \tag{23}$$

$$0 \leq R_{batdch} \leq R_{batdch,max} \tag{24}$$

$$Cap_{bat,min} \leq Cap_{bat} \leq Cap_{bat,max} \tag{25}$$

3.5 System control mechanism

The proper system control mechanism is necessary to enhance the system's reliability and maintain the system's operation. According to the power generation from solar energy, power charging from main grids, battery working principle, and power consumption from the homestay hotels, two typical modes of the system control mechanism are used as shown in Table 3. Mode I is adopted if the power generation from solar energy is lower than the demand of the homestay hotels. Among the different types of power supplies, renewable power generation from solar energy is regarded as the first option to meet the demand. If renewable power generation from solar energy is not enough, the battery storage is used to charge the system until it cannot charge anymore. If they still cannot meet the demand, the demand can be met by using the power charging from the main grids. Mode II is adopted if the power generation from solar energy is higher than the demand of the buildings. The power supply is solely renewable power generation. The surplus electricity from renewable power generation is stored in the battery storage until it reaches its rated capacity.

Table 3: Two modes of the system control mechanism

Mode	Judgment basis	Power supply	Power consumer
Mode I	$P_{solar}^{t} \leq P_{con}^{t}$	• Power generation from solar energy • Battery charging to system • Power charging from the main grids	Building demand
Mode II	$P_{solar}^{t} \geq P_{con}^{t}$	Power generation from solar energy	• Building demand • Battery storage

4. Microgrid performance assessment results and analysis

To demonstrate the impact of the occupancy rate on the system energy and economic performance, two cases (occupancy-based case and reference case) are listed and considered in the assessment results. The occupancy-based case is set to show the performance results concerning the real daily occupancy data of these homestay hotels. The reference case is set to reflect the performance results where the occupancy rate is assumed as 100% per day.

4.1 Load profile quantification concerning the occupancy rate

Fig. 5 shows the load profiles between the occupancy-based case and the reference case. Comparing the load profile of the occupancy-based case with the load profile of the reference case, their peak loads are the same (up to 120kW) but the load profiles of these two cases are quite different over time. The average load of the occupancy-based case is 36.9 kW while the average load of the reference case is 55.0 kW. Although the occupancy rate is about 58.9% of the aggregation of four hotels, the ratio of the load in the occupancy-based case to the load in the reference case is up to 67.1%. The reason is that the load is not a constant value over time. The difference in the daily occupancy rate leads to a large difference in the average load. For instance, the two scenarios have the same occupancy rate of 50%. In the first scenario, all the homestay hotels are booked per day in the first half-year while they are not booked in the last half-year. In this second scenario, the homestay hotels are booked for one day and they are not booked for the next day. As a result, both the average loads and the load profiles are drastically different between two cases.

The occupancy rate has a significant impact on the load profile but the load profile cannot be simply obtained by multiplying the average occupancy rate with the full-occupancy load profile. Instead of employing a simple average occupancy rate, an appropriate load profile must be calculated using daily or even shorter period occupancy data in order to close the gap between the ideal and actual conditions.

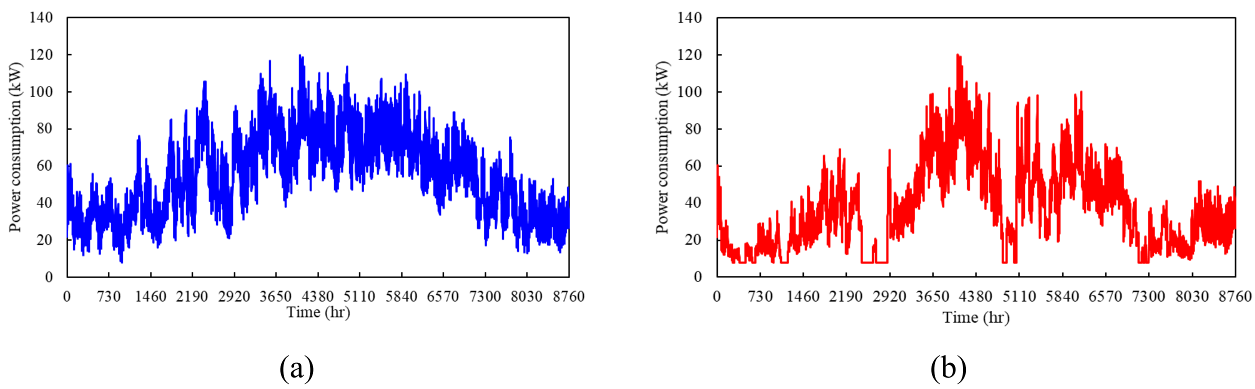


Fig. 5. Load profile between the occupancy-based case and reference case

4.2 System energy performance assessment

4.2.1 Renewable energy penetration

Fig. 6 shows the comparison results of the renewable energy penetration between the occupancy-based case and reference case considering the different PV areas with different battery capacities. The various percentages show the ratio of the battery capacity to the hourly maximum renewable power generation. The prevalence of renewable energy is significantly impacted by different PV areas. The renewable energy penetration can increase from 8% to 47% when the PV area goes from 100 m^2 to

800m^2. If the occupancy ratio is taken into account, the change in renewable energy penetration is from 5% to 39%.

Additionally, when the PV area is less than 300 m^2, the difference in battery capacity has a negligible effect on the penetration of renewable energy. Smaller PV installations (below 300 m^2) are unable to produce excess electricity to store in batteries, resulting in the same penetration of renewable energy across all battery sizes. When the PV area is enlarged, more surplus electricity from PV panels is stored and used to charge the homestay hotel system from the battery storage. As a result, the penetration of renewable energy is gradually impacted by battery storage. The largest difference in renewable energy penetration is obtained at 6.9% when a PV area of 800 m^2 is selected in the occupancy-based case.

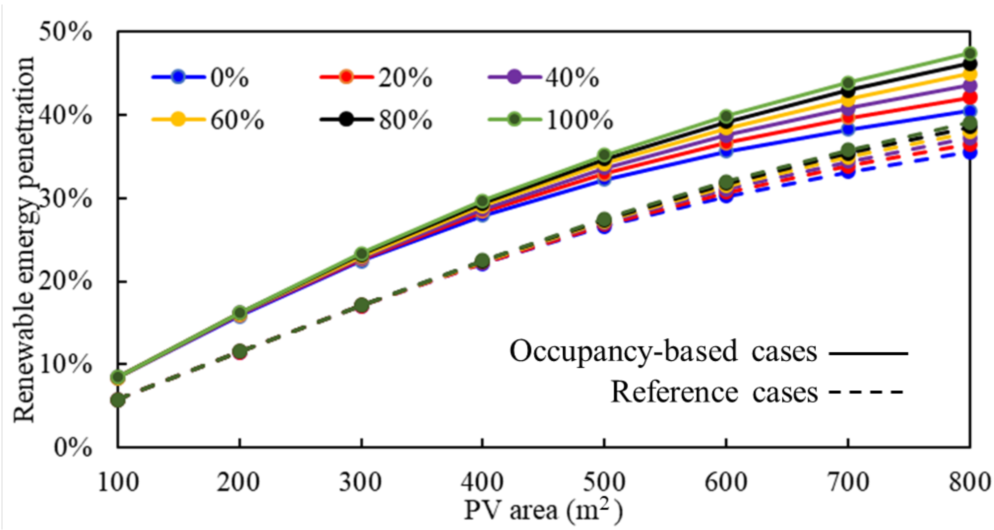


Fig. 6. Comparison results of the renewable energy penetration between the occupancy-based case and reference case considering the different PV areas with different battery capacities

Fig. 7 shows comparisons of the renewable power use efficiency between the occupancy-based case and reference case under different PV areas. With an increase in PV area, the efficiency of using renewable energy falls. Besides, it can be observed that the reference case uses renewable energy more effectively than the occupancy-based case under the specified PV areas. Since the load of the occupancy-based case is lower than the reference case's power consumption, more renewable energy generation must be directly consumed to meet demand. This improves the effectiveness of using renewable energy.

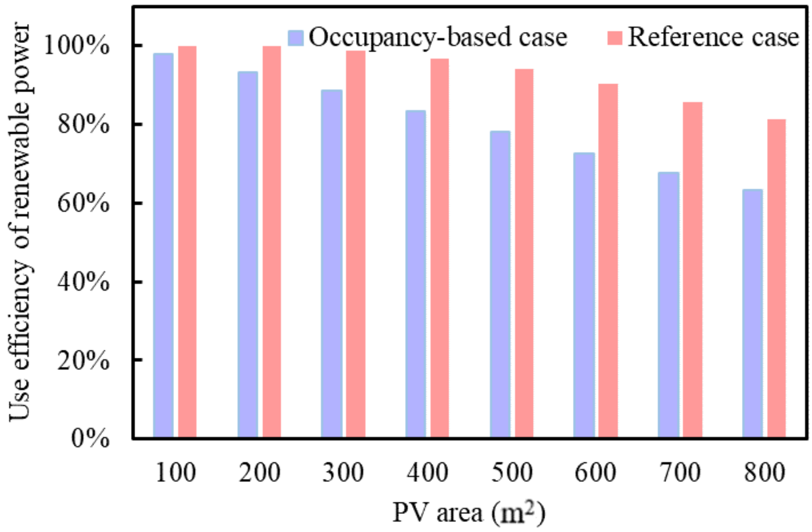


Fig. 7. Comparisons of the renewable power use efficiency between the occupancy-based case and reference case under different PV areas

4.2.2 Quantification of the grid impact performance for the solar homestay hotels

Quantification of the grid impact performance for the solar homestay hotels is of great value to providing the guideline for the operators in the main girds, which can provide support for the further energy performance assessment of the main grid reliability. Two major outputs (average charging power and peak load shedding) are involved in this assessment, where the detailed quantified assessment results are shown as follows:

Table 4 compares the average charging power from the main grids for the reference case and occupancy-based case using various PV areas and battery capacities. In terms of the PV area, as the PV area grows, the average charging power drops. Additionally, under various PV installation areas, the average charging power of the occupancy-based case is lower than the reference case. Without concerning occupancy rate, the extra charging power from the main grids is over-estimated, maximum of up to 70.6%.

As for the analysis of the battery storage capacity, the impact of the different battery capacities on the charging power from the main grids depends on the different PV areas. The battery has a tiny impact on the charging power from the main grids under a small PV area. This indicates that a smaller PV area is unable to generate enough electricity to both fulfil the demand and store any extra in batteries. Given a large PV area, the proper battery capacity can effectively decrease the power charging for the large PV area. For instance, under a given PV 800m^2 area, the power charging can effectively decrease about 13.8% and 5.9% respectively for the occupancy-based case and reference case. Overestimated electrical load in the reference case resulted in an underestimation of the battery's impact because the load calculation neglected to account for the occupancy rate.

Table 4: Comparison results of the average charging power between the occupancy-based case and reference case under different PV areas and battery capacities

Case	Charging power	PV area (m^2)							
		100	200	300	400	500	600	700	800
Occupancy-based case	P_{max} (kW)	33.83	31.09	28.69	26.71	25.17	23.99	23.05	22.31
	P_{min} (kW)	33.79	30.94	28.33	26.01	24.01	22.31	20.87	19.61
Reference case	P_{max} (kW)	51.81	48.66	45.63	42.83	40.36	38.35	36.75	35.44
	P_{min} (kW)	51.81	48.65	45.55	42.59	39.85	37.38	35.27	33.46

Fig. 8 shows peak load shedding under different PV areas with the best battery capacity and the largest difference in the peak load shedding under a given PV area with different battery capacities. The peak load shedding increases from 7.9% to 16.0% for the occupancy-based case and from 7.8% to 18.8% for the reference case respectively with the PV area increasing from 100 m^2 to 800 m^2. Enlarging the PV area can effectively increase peak load shedding. This can improve the major grids' reliability and lower the demand on the them during the peak period.

The impact of the battery capacity is quantified by using the largest difference in the peak load shedding under a given PV area. Under a given small PV area (below 300 m^2), the impact of the battery is tiny and it can be ignored. When the PV area is up to 800 m^2, the largest difference in the peak load shedding is up to 2.8% in the occupancy-based case when the proper battery capacity is set. The battery has a smaller impact (i.e., 0.5% of the largest difference of the peak load shedding) on increasing the peak shedding even if the PV area enlarges to 800m^2 in the reference case. The over-estimated electrical load in the reference case leads to the deviation of the assessment performance concerning the battery storage contribution.

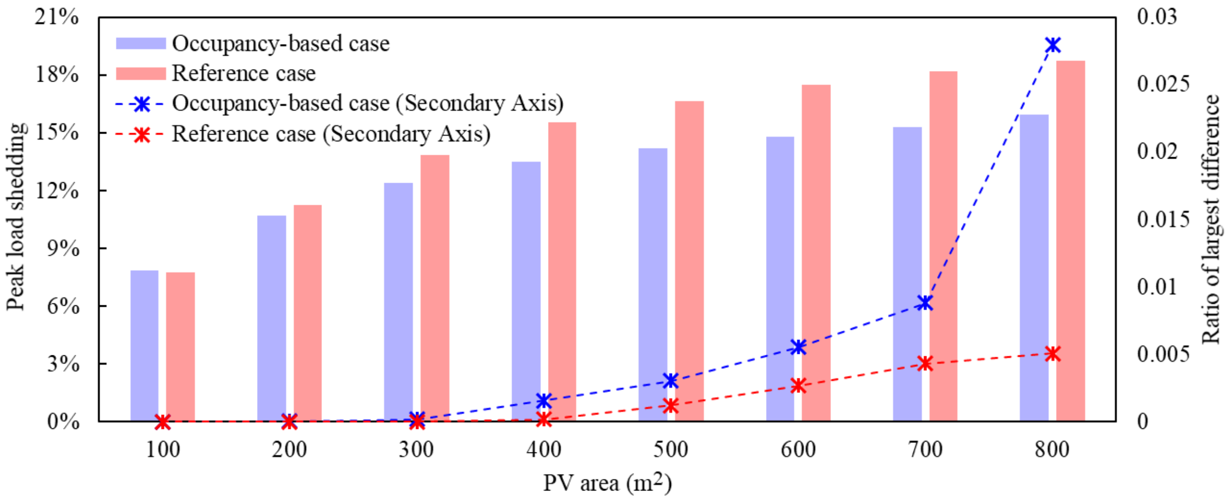


Fig. 8. Peak load shedding under different PV areas with the best battery capacity and the largest difference in the peak load shedding under a given PV area with different battery capacities

To directly depict the impact of the solar homestay hotel with different battery capacities on the peak load shedding during the operation, Fig. 9 shows the daily peak load shedding with two different battery capacities (0% and 100% of the maximum hourly renewable power generation) under given 800 m^2 PV area. To better demonstrate the battery capacity impacts, the maximum 800 m^2 PV area was chosen, which has a large possibility to produce surplus electricity. Among these two scenarios (i.e., two battery capacities), the larger battery capacity can effectively address the intermittent nature of power generation from solar energy and achieve peak load shedding effectively, even though the power generation from PV panels is the same.

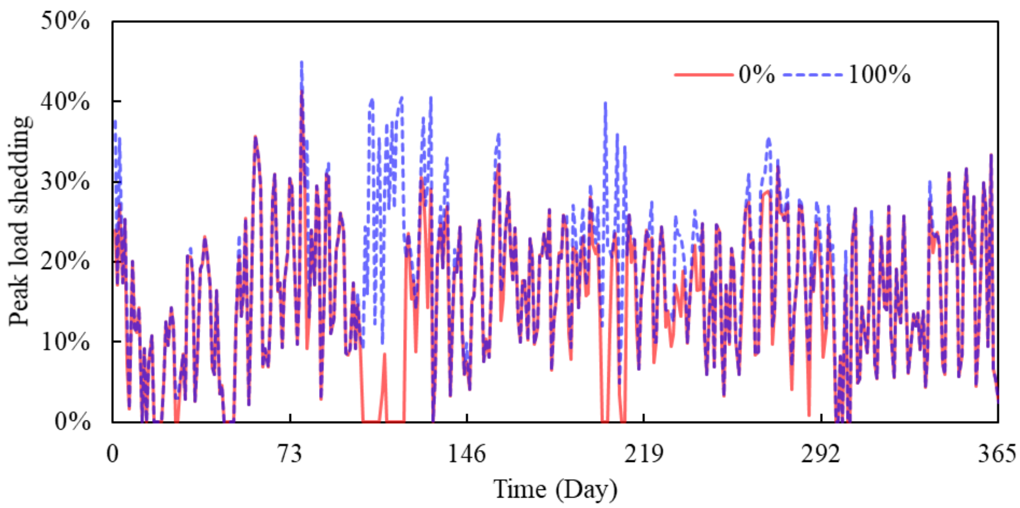


Fig. 9. Annual daily peak load shedding results under two battery capacities

To directly depict the impact of the solar homestay hotel with different PV areas on the peak load shedding during the operation, Fig. 10 shows the daily peak load shedding with three different PV areas (100 m^2, 400 m^2, and 800 m^2). Battery storage is not utilized here in order to more clearly show how the various PV areas affect peak load shedding. Peak load shedding can be successfully increased by expanding the PV area. The peak load almost exactly matches the solar power generation's temporal distribution. As a result, a sizable PV area can significantly reduce peak load.

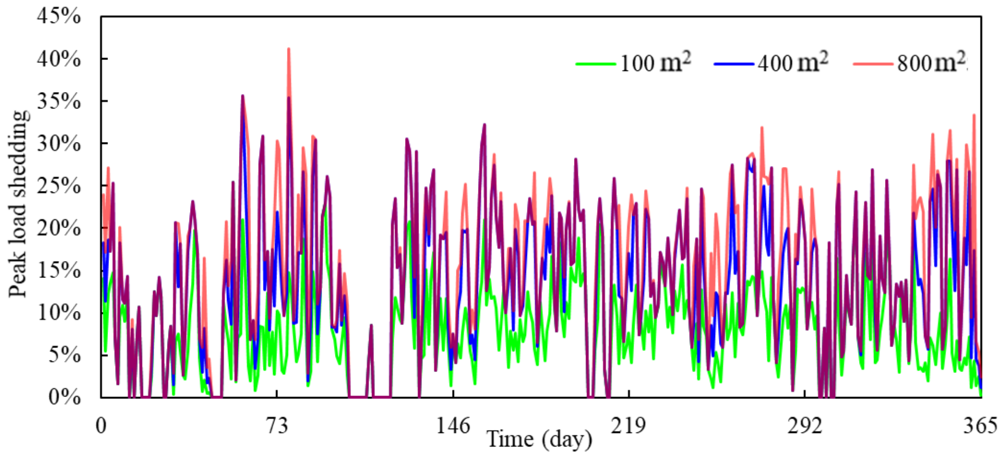


Fig. 10. Annual daily peak load shedding results under given three PV areas

4.3 System economic performance assessment

To provide a comprehensive economic performance assessment considering two major variables (PV panel and battery storage). The range of the PV area from 100 m^2 to 800 m^2 is included in this assessment. The battery capacity is determined as the optimum value under given a PV area, where the range of the battery capacity is determined according to Table 2. Table 5 shows these energy portfolios considering the different PV areas with their optimum battery capacity. These energy portfolios are tested in the following economic performance assessment. Since the battery capacity is selected as the optimum value under a given PV area, the following assessment focuses on the impact of the different PV areas on economic performance. As for the occupancy-based case, the battery storage has a tiny impact when the PV area is lower than 300 m^2. With the larger area of the PV installation, the battery capacity is increasing. As for the reference case, due to the power consumption over-estimated, the selections of the battery capacity are different accordingly. The battery storage is zero with the PV area below 500 m^2.

Table 5: The energy portfolios considering different PV areas and their optimum battery capacities

in these two cases

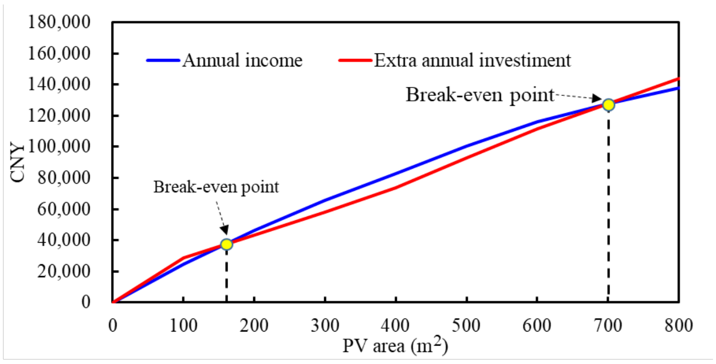
Energy portfolios	Occupancy-based case		Energy portfolios	Reference case	
	PV area (m^2)	Battery capacity (kWh)		PV area (m^2)	Battery storage (kWh)
Portfolio 1	100	0	Portfolio 1	100	0
Portfolio 2	200	0	Portfolio 2	200	0
Portfolio 3	300	0	Portfolio 3	300	0
Portfolio 4	400	16	Portfolio 4	400	0
Portfolio 5	500	70	Portfolio 5	500	0
Portfolio 6	600	120	Portfolio 6	600	24
Portfolio 7	700	140	Portfolio 7	700	70
Portfolio 8	800	160	Portfolio 8	800	144

4.3.1 Break-even analysis of solar homestay hotel

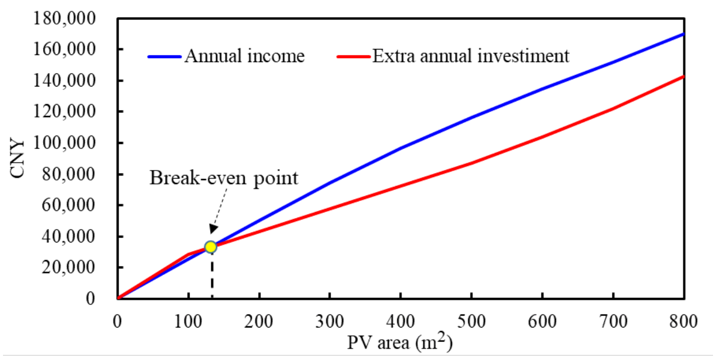
The graphic form of the break-even points in these two cases (i.e., occupancy-based case and reference case) are shown in Fig. 11 (a) and Fig. 11 (b), respectively. To find out the optimum energy portfolios, where the solar homestay hotel system becomes economic, a break-even analysis is performed. The annual income and extra annual investment are presented as the major variables.

As for the occupancy-based case, two BEPs of the occupancy-based case are obtained at 160 m^2 and 700 m^2 of the PV areas. These two PV area values are found by equating the costs of the above-mentioned annual income and extra annual investment. If the PV area located between 160 m^2 and 700 m^2 is selected, the solar homestay hotel system becomes more cost-effective than the homestay hotel building without PV installation.

On the other hand, for the reference case, only one BEP is obtained at 130 m^2 of the PV area. In the reference case, if the selected PV area is above 130 m^2, the solar homestay hotel system becomes more economical than the homestay hotel building without PV installation. The larger electrical load of the reference case causes higher renewable power use efficiency of the reference case. However, it cannot reflect the real case. The reference case's overestimation could be the reason why the optimal PV area isn't actually the best outcome.



(a) Occupancy-based case



(b) Reference case

Fig. 11. Break-even analysis of solar homestay hotel

4.3.2 Levelized cost of energy quantification

Levelized cost of energy quantification can effectively provide a graphic scheme of the difference in the electricity price per kilowatt under the different PV areas, as shown in Fig. 12. The real electricity price is according to the Hainan real electrical price [35], as shown in the green dash line. The results are consistent with the previous break-even analysis. The largest cost savings of the occupancy-based case and reference case are 6.4% and 14.8% respectively, where the optimum PV areas are 400 m^2 and 600 m^2 in these two cases. The deviation of the assessments by using a 100% occupancy rate can be addressed and the obtained optimum PV area is corrected.

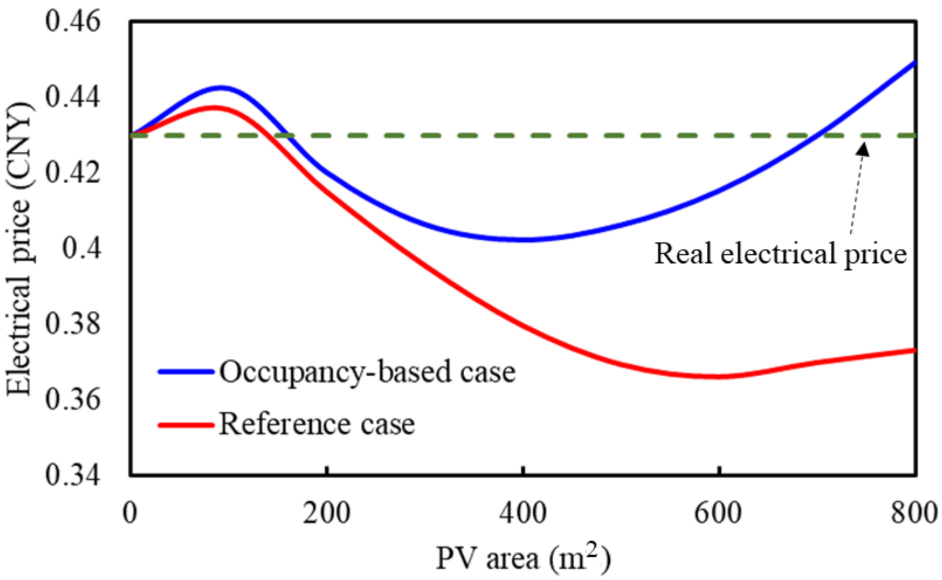


Fig. 12. Electricity price quantification results under different PV areas for these two cases

5. Conclusion

In this paper, a comprehensive and quantitative assessment approach of small-scale solar homestay hotel systems is proposed. This approach can effectively assess energy and economic performance simultaneously. The dynamic daily occupancy rate is considered in the energy and economic assessment. The proposed assessment approach is tested and verified on four small-scale homestay hotels in the tropical region. According to the assessment results, the main findings can be concluded as follows:

- The proposed assessment approach can comprehensively quantify the impacts of the PV areas and battery capacities on the system performance in terms of energy and economics. Instead of the optimum energy portfolios (PV area 600 m^2 and battery capacity 24 kWh) obtained from conventional assessment results, the optimum PV area and battery capacity are 400 m^2 and 16 kWh according to the occupancy-based assessment results.
- As for the assessment results of the solar homestay hotel energy performance, the renewable energy penetration can be maximum at 47% in the reference case while the maximum value is up to 39% in the occupancy-based case. Besides, the average charging power of the occupancy-based case is lower than the reference case under different PV areas. Without concerning occupancy rate, the extra charging power from the main grids is over-estimated, maximum of up to 70.6%.
- In the economic assessment of the solar homestay hotel, break-even analysis is selected and used to assess the economic performance (annual income and extra annual investment) under different energy portfolios. The LOCE is quantified under different energy portfolios. The PV area between 160 m^2 and 700 m^2 can make the solar homestay hotel system more economical than the homestay hotel building without PV installation.
- The large fluctuation of the occupancy rate is considered and analyzed in the typical homestay hotels on electrical load impact. According to the case study, the average occupancy rate is obtained as 58.9% while the ratio of the occupancy-based load to the load with a 100% of occupancy rate is up to 67.1%. Using 100% of the occupancy rate or a simple annual average occupancy rate value leads to a large deviation in the energy and economic performance assessments. This provides inaccurate guidelines and recommendations for the decision-makers

in the further design and control stages.

In concluding the paper, we point out a few limitations of the current study and two particular opportunities for future research. First, the proposed comprehensive and quantitative assessment approach of small-scale solar homestay hotel systems may be restricted to the city sampled in this study. As homestay hotel continues to proliferate, future research can examine additional buildings, especially tourism-related businesses such as integrating associated buildings into account (e.g., restaurants and hotels), retail buildings (e.g., neighbourhood shops), and travel services (e.g., train and flight) to further deepen our understanding of the energy consumptions of homestay hotel buildings. Second, we build upon past research and industry evidence to suggest that the hotel occupancy rate is important because the data of the hotel occupancy rates can help correct the deviation of the hotel load calculation and avoid obtaining overestimated and/or underestimated assessments of the energy and economic performance. Since our data do not contain direct fine-grained measures of energy consumption from hotel guests, we collect the daily occupancy rates to estimate the volatility in electricity demand. Future research could delve deeper into energy usage of guests to examine the assessment approach of small-scale solar homestay hotel systems.

Acknowledgement

The research presented in this paper is financially supported by A and B in The Hong Kong Polytechnic University.

References

[1] D.L. McCollum, W. Zhou, C. Bertram, H.-S. De Boer, V. Bosetti, S. Busch, J. Després, L. Drouet, J. Emmerling, M. Fay, Energy investment needs for fulfilling the Paris Agreement and achieving the Sustainable Development Goals, Nature Energy, 3 (7) (2018) 589-599.

[2] T.S. Schmidt, S. Sewerin, Technology as a driver of climate and energy politics, Nature Energy, 2 (6) (2017) 1-3.

[3] B. Bramwell, J. Higham, B. Lane, G. Miller, Twenty-five years of sustainable tourism and the Journal of Sustainable Tourism: looking back and moving forward, in, Taylor & Francis, 2017, pp. 1-9.

[4] J. Loehr, S. Becken, The tourism climate change knowledge system, Annals of Tourism Research, 86 (2021) 103073.

[5] D. Scott, S. Gössling, A review of research into tourism and climate change-Launching the annals of tourism research curated collection on tourism and climate change, Annals of Tourism Research, 95 (2022) 103409.

[6] K. Ásványi, K. Juhász-Dóra, M. Jászberényi, G. Michalkó, Literature review of renewable energy in the tourism industry, Journal of Environmental Management & Tourism, 8 (2 (18)) (2017) 476.

[7] J. Nematian, I. Rahimi, Feasibility study of using renewable energies in Iranian Seas: A comparative study, Renew. Energy, 189 (2022) 383-391.

[8] C.J. Corbett, D.A. Kirsch, International diffusion of ISO 14000 certification, Production and operations management, 10 (3) (2001) 327-342.

[9] M. Farrokhi, N. Javani, R. Motallebzadeh, A. Ebrahimpour, Dynamic simulation and optimization of a novel energy system with Hydrogen energy storage for hotel buildings, Energy, 257 (2022) 124586.

[10] M. Lamagna, B. Nastasi, D. Groppi, C. Rozain, M. Manfren, D.A. Garcia, Techno-economic assessment of reversible Solid Oxide Cell integration to renewable energy systems at building and district scale, Energy Convers. Manage., 235 (2021) 113993.

[11] H. Meschede, H. Dunkelberg, F. Stöhr, R.-H. Peesel, J. Hesselbach, Assessment of probabilistic distributed factors influencing renewable energy supply for hotels using Monte-Carlo methods, Energy, 128 (2017) 86-100.

[12] M. Beccali, P. Finocchiaro, M. Ippolito, G. Leone, D. Panno, G. Zizzo, Analysis of some renewable energy uses and demand side measures for hotels on small Mediterranean islands: A

case study, Energy, 157 (2018) 106-114.

[13] D. Wang, J. Meng, T. Zhang, Post-evaluation on energy saving reconstruction for hotel buildings, a case study in Jiangsu, China, Energy Build., 251 (2021) 111316.

[14] P.O. Oluseyi, O.M. Babatunde, O.A. Babatunde, Assessment of energy consumption and carbon footprint from the hotel sector within Lagos, Nigeria, Energy Build., 118 (2016) 106-113.

[15] J. Luo, H. Li, S. Wang, A quantitative approach and simplified generic transient motor startup power models for microgrids security assessment, Sustainable Cities Soc., (2022) 103998.

[16] V. Bianco, D. Righi, F. Scarpa, L.A. Tagliafico, Modeling energy consumption and efficiency measures in the Italian hotel sector, Energy Build., 149 (2017) 329-338.

[17] P. Xu, E.H.-W. Chan, Q.K. Qian, Success factors of energy performance contracting (EPC) for sustainable building energy efficiency retrofit (BEER) of hotel buildings in China, Energy policy, 39 (11) (2011) 7389-7398.

[18] S.P. Pieri, M. Santamouris, Identifying energy consumption patterns in the Attica hotel sector using cluster analysis techniques with the aim of reducing hotels' CO2 footprint, Energy Build., 94 (2015) 252-262.

[19] M. Vujošević, A. Krstić-Furundžić, The influence of atrium on energy performance of hotel building, Energy Build., 156 (2017) 140-150.

[20] J.T. Luo, M.M. Joybari, K. Panchabikesan, Y. Sun, F. Haghighat, A. Moreau, M. Robichaud, Performance of a self-learning predictive controller for peak shifting in a building integrated with energy storage, Sustainable Cities Soc., 60 (2020) 102285.

[21] J.T. Luo, M.M. Joybari, K. Panchabikesan, F. Haghighat, A. Moreau, M. Robichaud, Parametric study to maximize the peak load shifting and thermal comfort in residential buildings located in cold climates, J. Energy Storage, 30 (2020) 101560.

[22] K. Kusakana, Optimal energy management of a grid-connected dual-tracking photovoltaic system with battery storage: Case of a microbrewery under demand response, Energy, 212 (2020) 118782.

[23] W.T. Chong, X.H. Wang, K.H. Wong, J.C. Mojumder, S.C. Poh, L.H. Saw, S.H. Lai, Performance assessment of a hybrid solar-wind-rain eco-roof system for buildings, Energy Build., 127 (2016) 1028-1042.

[24] A. Aldawoud, R. Clark, Comparative analysis of energy performance between courtyard and atrium in buildings, Energy Build., 40 (3) (2008) 209-214.

[25] B. Habeebullah, Economic feasibility of thermal energy storage systems, Energy Build., 39 (3) (2007) 355-363.

[26] G. Díaz, J. Gómez-Aleixandre, J. Coto, Dynamic evaluation of the levelized cost of wind power generation, Energy Convers. Manage., 101 (2015) 721-729.

[27] J. Zhang, L. Ji, Optimization of Daylighting, Ventilation, and Cooling Load Performance of Apartment in Tropical Ocean Area Based on Parametric Design, Adv. Civ. Eng., 2021 (2021).

[28] A.K. Daud, M.S. Ismail, Design of isolated hybrid systems minimizing costs and pollutant emissions, Renew. Energy, 44 (2012) 215-224.

[29] R. Venkateswari, S. Sreejith, Factors influencing the efficiency of photovoltaic system, Renewable Sustainable Energy Rev, 101 (2019) 376-394.

[30] C. Zhuang, K. Shan, S. Wang, Coordinated demand-controlled ventilation strategy for energy-efficient operation in multi-zone cleanroom air-conditioning systems, Build. Environ., 191 (2021) 107588.

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

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

[33] G.-F. Fan, X.-R. Jin, W.-C. Hong, Application of COEMD-S-SVR model in tourism demand forecasting and economic behavior analysis: The case of Sanya City, Journal of the Operational Research Society, 73 (7) (2022) 1474-1486.

[34] H. Li, S. Wang, Coordinated optimal design of zero/low energy buildings and their energy systems based on multi-stage design optimization, Energy, 189 (2019) 116202.

[35] S. Qiu, K. Wang, B. Lin, P. Lin, Economic analysis of residential solar photovoltaic systems in China, Journal of Cleaner Production, 282 (2021) 125297.

Abbreviations

BEA	Break-even analysis
BEP	Break-even point
COP	Coefficient of performance
LCOE	Levelized cost of energy
PLS	Peak load shedding
PV	Photovoltaics
REP	Renewable energy penetration
RPUE	Renewable power use efficiency
SHH	Solar homestay hotel

Nomenclature

η_{PV}	Overall efficiency of PV panels	P_{peak}^{D}	Daily peak charging power
A_{PV}	Total area of PV panels	P_{tot}^{t}	Total load
$C_{fac,k}$	The initial cost of the kth facility	$P_{hotel,n}^{t}$	Load of the homestay hotel
C_{opt}	Operation cost	$P_{cool,hotel}^{t}$	Cooling load of the homestay hotel
C_{ini}	Initial cost	$P_{ur,t}$	The used renewable power generation
C_{man}	Maintenance cost	$P_{ren,t}$	Renewable power generation
C_{ic}	Annual income	Rad	Solar radiation per area
C_{ei}	annual extra investment	REP	Renewable energy penetration
$C_{LCOE,real}$	Real levelized cost of energy	R_{PLS}^{d}	Daily peak load shedding
$C_{LCOE,equ}$	Equivalent levelized cost of energy	$R_{ocp,n}^{D}$	Occupancy rate
E_{tot}	Total energy consumption	$R_{batch,max}$	Maximum charging rate
K_{PV}	Temperature coefficient	$R_{batdch,max}$	Maximum discharging rate
$P_{ot,hotel}^{t}$	Other electrical loads	T_{ref}	PV panels reference temperatures
P_{con}^{t}	Power consumption	T_{amb}	Ambient temperature
P_{avi}^{t}	Available power generation	Y_k	The total years of the life cycle
P_{PV}	Power generated from solar radiation		