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Energy-Saving Operation Strategy for Hotels Considering the Impact of COVID-19 in the Context of Carbon Neutrality

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Abstract: With the advent of the post-epidemic era, the energy consumption characteristics of hotels have changed, which has an important impact on urban energy conservation. In order to contribute to the goal of carbon neutrality, this study discusses the energy-saving operation strategy of hotels considering the impact of the COVID-19 epidemic. Based on the energy consumption characteristics of large public buildings, this paper analyzes the energy consumption distribution and operation characteristics of hotel buildings in detail. By collecting energy consumption data from five typical large hotel buildings in a tourist city in southern China from 2018 to 2022, the impact of COVID-19 on hotel energy consumption and hotel business characteristics was discussed in detail. Combined with the economic development characteristic in the post-epidemic era, this paper explores the energy-saving strategies that hotels can adopt in the context of normalized epidemic prevention and control and obtains the optimal path of low-carbon economic operation of hotel buildings. This study reveals the energy consumption characteristics and energy-saving potential of hotel buildings, and provides enlightenment for hotel management and low-carbon development in the post-epidemic era.

Keywords: hotel building; energy conversation; energy consumption; carbon emission; COVID-19 impact; carbon neutrality

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1. Introduction

With the continuous advancement of social industrialization and accelerating urban modernization, problems such as the energy crisis and resources and ecological environment deterioration have gradually intensified, seriously affecting the sustainable development of society [1]. In addition, the outbreak of the COVID-19 epidemic has further affected the way of life and production of human beings [2], which has also had an important impact on hotel energy consumption. As a result, it is essential to explore efficient energy conservation and emission reduction strategies. A hotel's operation will consume much energy and generate a lot of carbon emissions, which also contains great energy-saving potential [3]. Therefore, in order to promote the construction of low-carbon cities, it is essential to explore the energy-saving operation strategies of hotels considering the impact of the COVID-19 epidemic in the context of carbon neutrality.

In recent years, the building industry has developed rapidly. According to the statistics of the "China Building Energy Conservation Association", the total building area of China has reached 43 billion square meters. Among them, large-scale public buildings only account for 5%, but their energy consumption is up to 25% of the total social energy consumption [4]. As a typical large-scale public building, hotels have high energy consumption and carbon emissions [5]. It is estimated that the energy consumption of star hotels accounts for 22.32% of the total energy consumption in the tourism industry, and the carbon emissions account for 41.5% of the total emissions in the tourism industry [6]. Currently, the energy utilization efficiency of hotel buildings in China is relatively low.

Specifically, the average power consumption of hotel buildings is more than 10 times that of residential buildings, while water consumption is more than 5 times that of residential buildings [7].

In order to improve the efficiency of energy conservation and emission reduction (ECER) in hotels, scholars have carried out a series of studies on the energy-saving operation of hotels. For example, in terms of hotel building design, the existing research mainly discusses the energy-saving measures of hotel buildings from the perspectives of maximizing natural ventilation [8], lighting design [9], and thermal insulation design [10]. In terms of rational use of energy, hotel buildings use a lot of renewable energy sources (RES) [11], specifically some hotels demonstrate the application of roof photovoltaics [12]. In addition, many hotels also optimize the use of resources inside the building, so as to achieve energy-saving operation. For example, energy-saving variable frequency air conditioners [13], automatic energy-saving lighting [14], and building energy optimization management system [15] are all used to promote the low-carbon operation of the hotel while meeting the comfort requirements of users. However, with the continuous promotion of the carbon neutral goal, these studies have limitations in comprehensively discussing the energy-saving operation of hotels. In particular, the promotion of normalized COVID-19 epidemic prevention and control has brought new challenges and opportunities to the energy-saving operation of hotels.

In addition, the outbreak of COVID-19 epidemic has seriously influenced and changed the hotel operation feature [16]. In order to explore the impact of the COVID-19 epidemic on hotel energy-saving operation, scholars also conducted some analysis on the operation characteristic of hotel buildings during the epidemic. For example, the correlation analysis between user satisfaction and energy consumption during the epidemic [17], the correlation analysis between hotel design and operation during the epidemic [18], and the operating characteristics of hotels during the epidemic [19]. In addition, other studies include the impact of COVID-19 on hotel architectural design in terms of employee performance [20], or the impact of COVID-19 on hotel booking willingness [21]. However, these studies mainly focused on the impact of COVID-19 on hotel operation and service characteristics, or mainly analyzed the impact of COVID-19 on the overall energy consumption of buildings but lacked a separate analysis of specific hotels. Whether it is the epidemic outbreak or normalization period, it impacts the operation of hotel buildings significantly. Therefore, as an essential field of ECER, it is crucial to analyze the energy consumption and carbon emission characteristics of hotel buildings with high investment, high consumption and high pollution.

Based on the above problems, in order to fill in the gaps in existing research, this study discussed the energy-saving operation characteristics of hotels in detail considering the impact of the COVID-19 epidemic in the context of carbon neutrality. Then, prospect of the low-carbon economy operation strategy for hotels is put forward to provide technical and theoretical support for the construction and development of near zero-carbon hotel buildings and promote the realization of the global carbon neutrality goal. The main contributions of this paper are as follows:

(1) Based on the energy consumption characteristics of large-scale public buildings, the energy consumption distribution and operation characteristics of hotel buildings is analyzed in detail.
(2) By collecting energy consumption data from five typical hotel buildings in a tourist city in southern China from 2018 to 2022, the impact of COVID-19 on hotel energy consumption and business characteristics is analyzed in detail.
(3) Combined with the characteristics of economic development in the post-epidemic era, the energy-saving strategies that can be adopted by hotels during the period of epidemic normalization prevention and control are discussed, and the optimization path of low-carbon economic operation of hotel buildings is obtained.

The primary research method of this paper is as follows: through research cooperation with five large hotels in a tourist city in southern China, part of the energy consumption

data of these hotels from 2018 to 2022 are collected, and detailed data processing and analysis of this information are carried out. These data are from the measured data of both parties. It is worth noting that some data may have errors due to the influence of weather, human behavior, and other factors in the data collection process. However, they do not affect the overall trend of the results. The remainder of this paper is organized as follows: Section 2 mainly introduces the overall energy consumption distribution and operation characteristics of the hotel building. Section 3 analyzes the energy consumption characteristics of the surveyed typical hotels before and after the COVID-19 pandemic. Based on the content of Section 3, Section 4 further discusses the energy-saving measures and low-carbon operation strategies of hotels under the post-epidemic era. Section 5 is the conclusion.

2. Energy Consumption Characteristics of Hotel Buildings

2.1. Energy Consumption Distribution of Large Public Buildings

Hotels, usually as a kind of typical large-scale public building, have a typical energy consumption distribution. It is of great significance to analyze large-scale public buildings' energy consumption distribution characteristics. The energy consumption of large public buildings is generally dominated by electricity, supplemented by natural gas, coal, steam and municipal hot water, which are characterized by high energy consumption density and great energy-saving potential [22]. Among them, the annual energy consumption of office buildings, hotels and shopping malls is about 100 kW/(m^2·a), 100–200 kW/(m^2·a) and 200–300 kW/(m^2·a), respectively [23]. As shown in Figure 1, the energy consumption of large public buildings is mainly distributed in heating, ventilation and air conditioning (HVAC), lighting sockets, power equipment and special function equipment. Among them, about 50–60% of the energy is consumed in HVAC, and about 20–30% is for lighting [24].

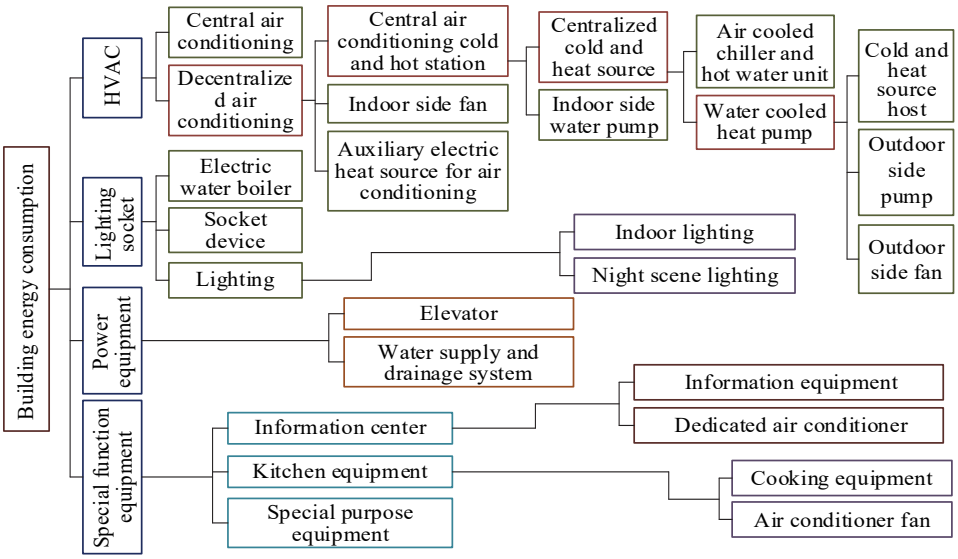

Figure 1. Energy consumption distribution characteristics of large public buildings.

From the perspective of the whole life cycle, buildings can be counted as the industry with the most significant carbon emission in China [25]. According to a report by China Building Energy Efficiency Association, in 2019, the whole process of building energy consumption in China accounted for 45% of the total, and the carbon emission accounted for 50.6% of the total carbon emission [26]. Figure 2 shows the energy consumption distribution characteristics of large public buildings in each stage from 2010 to 2019. Among them, the energy consumption of the building operation process is increasing yearly. In addition, from the perspective of building materials production, steel, cement and glass have high energy consumption and carbon emissions. In terms of the subsequent use of the buildings, the

carbon emissions generated by daily heating, electricity, etc., should not be underestimated. In 2020, the COVID-19 outbreak caused a dramatic change in the distribution of energy consumption in buildings. Among them, the energy consumption of large public buildings decreased significantly (except for some hotels expropriated by the government), while the energy consumption of residential buildings increased significantly [27]. Although the overall energy consumption of buildings was in a state of decline in 2022, with the epidemic prevention and improvement in situation control, the rapid advancement of urbanization, and the in-depth adjustment of the industrial structure, the energy consumption and carbon emissions of the construction industry will further increase under the post-epidemic era.

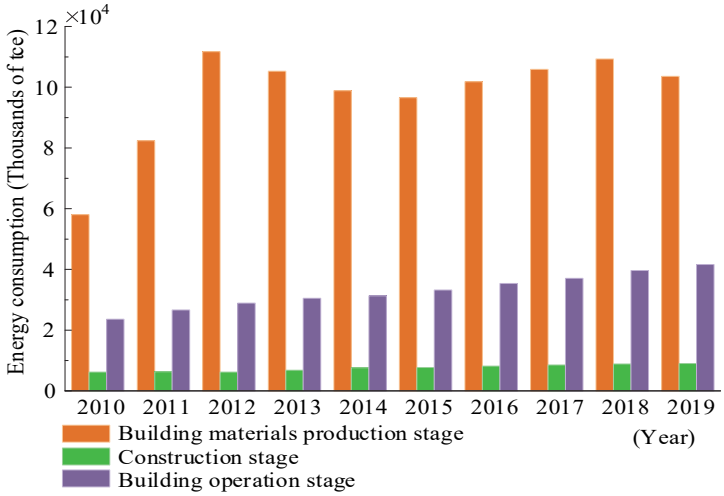

Figure 2. Energy consumption distribution of large public buildings in different stages.

2.2. The Quantity Distribution and Operation Characteristics of the Hotel

In recent years, the improvement of the tourism economy has promoted the continuous development of the hotel industry. According to the National Tourism Administration's statistics on hotels in China [28], the number of hotels with different stars in China from 2015 to 2021 is shown in Figure 3. Among them, the number of three-star hotels is the largest, and the overall number shows a downward trend. Due to the outbreak of COVID-19 in February 2020, the emergency policy of shutting down the country had a significant impact on the hotel industry. From 2019 to 2021, the total number of hotels declined by about 5.9% and 9.73%, respectively. Among them, the primary decline mainly occurred in the number of two-star to four-star hotels, while the number of five-star hotels changed little. Although the number of one-star hotels is small, the decline rate reached 53.33% in 2020–2021 as well.

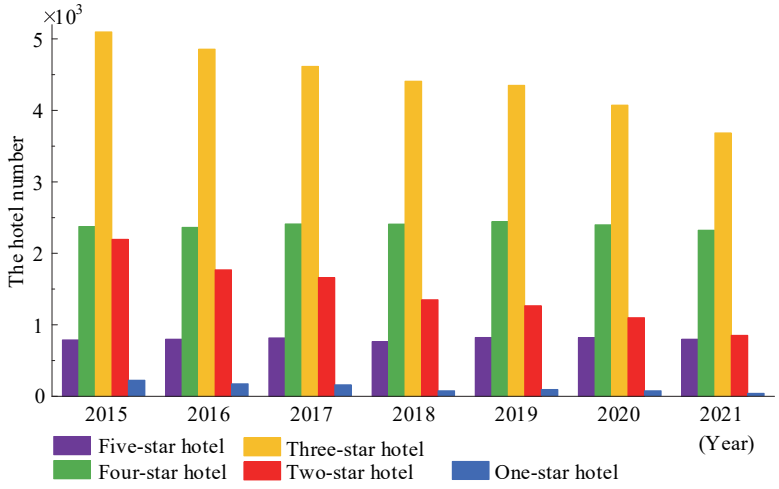

Figure 3. Changes in the number of different star-rated hotels in China from 2015 to 2021.

Figure 4 analyzes the operating conditions of the hotel from 2015 to 2021. From 2015 to 2019, the overall operating income, room income and catering income of the hotel maintained a stable value, and the fluctuation range was small. Due to the COVID-19 pandemic, these incomes showed a definite downward trend of 36.33% from 2019 to 2020, and gradually picked up in 2021. This transition is because, with the reasonable control of the epidemic, the city gradually resumed work and production, so that the business status of hotels began to recover. Although the business situation of the hotel has gradually improved and the room occupancy rate has gradually increased under the premise of strictly implementing normalized epidemic prevention and control measures, the hotel is still in a loss state, which reasonably explains the reason for the decrease in the number of hotels.

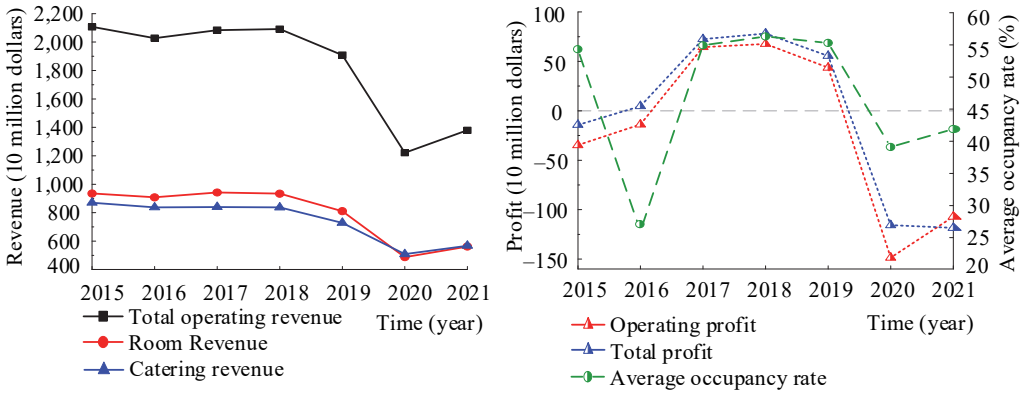

Figure 4. The business status of hotels in China from 2015 to 2021.

2.3. The Overall Energy Consumption Level of Hotel Buildings

According to statistics, before the outbreak of COVID-19, the annual electricity consumption of hotels in China was usually 0.3~1.5 million kWh, and the annual electricity consumption of star hotels was 1~10 million kWh [29]. China has a wide geographical distribution. Due to the different geographical locations, climate conditions and tourism development, the energy consumption of hotel buildings in different regions varies greatly. As shown in Figure 5a, the average energy consumption of southern cities with hot summers and warm winters (such as Hainan) is about 150 kWh/(m^2·a) [30], while that of northern cities with cold weather (such as Xi 'an) is about 135.6 kWh/(m^2·a). The difference between the two hotels is 10.62%. Although the two cities are both rapidly developing tourism cities, the energy consumption gap is still significant. In addition, in Beijing, Shanghai, Guangdong, Shenzhen and other areas with rapid economic development, the average energy consumption of hotel buildings is high, usually above 160 kWh/(m^2·a). These cities have a multitude of business contacts and usually require a high level of service from hotels, which leads to higher energy consumption in hotel buildings.

It is worth noting that hotel differences, such as star rating, service level and open function, will also have different impacts on hotel energy consumption in the same area [31]. For example, the energy consumption of different star hotels in Shanghai is 42.2~347.9 kWh/(m^2·a), with a maximum difference of 724.41%. The difference of power consumption between five-star and four-star hotels in Wenzhou is 33.34 kWh/(m^2·a), while the energy consumption difference between hotel buildings in Dalian also reached 81.24%. In addition, due to the impact of the COVID-19 pandemic, hotel energy consumption in all regions showed a significant trend of decline. Due to the influence of lockdown policies and population aggregation, the energy consumption of hotels in different regions also varies significantly. For example, most hotels in Wuhan, the worst-hit area, were requisitioned as government quarantine sites, so their energy consumption during the pandemic was very high. The energy consumption of hotels in other areas is significantly different according to whether it is expropriated.

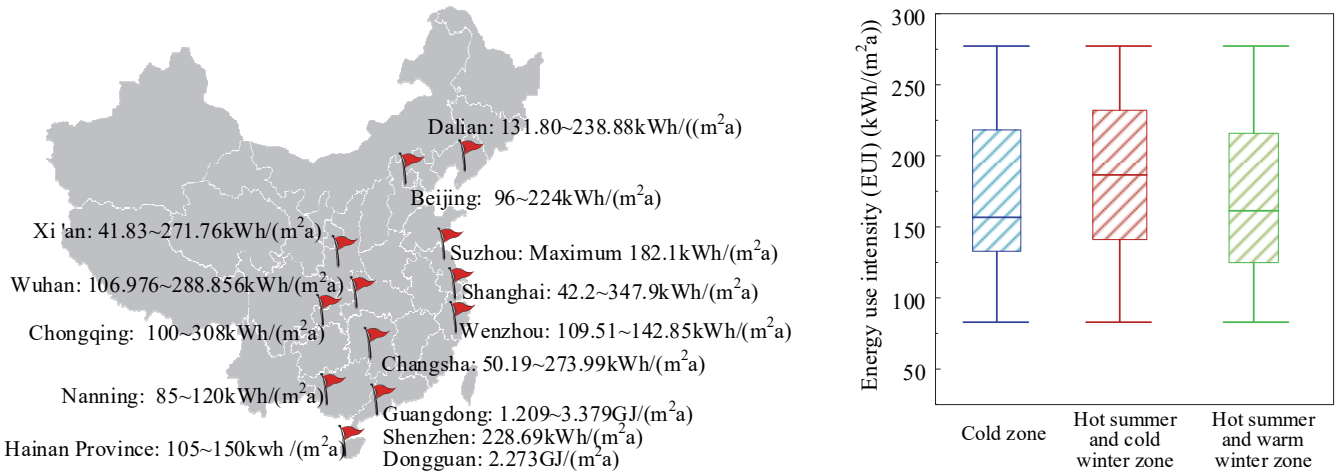

Figure 5. Overall energy consumption distribution characteristics of hotel buildings: (**a**) Energy consumption distribution characteristics of hotel building in different regions; (**b**) Energy consumption distribution characteristics of hotel building in different regions.

Figure 5b shows the energy utilization intensity (EUI) characteristics of hotels in different regions in China. The EUI of cold regions, hot summer and cold winter regions and hot summer and warm winter zone are 159 kWh/(m^2·a), 179 kWh/(m^2·a) and 156 kWh/(m^2·a), respectively. The maximums and minimums of energy consumption in the three zones are similar, approximately 276 kWh/(m^2·a) and 82 kWh/(m^2·a) [32]. It reveals that the minimum energy consumption in each climate zone is basically the same. Severe regions have colder winters and require much energy for heating. Regions with hot summers and warm winters have more extended periods of high temperatures in summer, requiring energy for cooling. Therefore, energy consumption in these two regions is higher than in regions with hot summers and cold winters.

3. Case Study of Hotel Energy-Saving Operation Considering the Impact of COVID-19

3.1. Detailed Energy Consumption Analysis of the Hotel

3.1.1. Evolution Characteristics of Hotel Energy Consumption during COVID-19

In order to explore and deeply analyze the ECER potential of hotel buildings, the study conducted research in cooperation with five large hotels and two Bed and Breakfasts (B&B) in a tourist city in southern China, and accomplished investigation and analysis of these hotels' energy consumption data. The detailed parameters of these hotel buildings are shown in Table 1. All the data analyzed in this paper come from the measured data of both parties. However, due to the interference of weather, human behavior and other factors in data measurement and collection process, some data have specific errors, but they do not affect the overall trend of the results.

The average electricity consumption of the five large hotels and two B&Bs investigated in this paper from the first quarter of 2018 to the third quarter of 2022 is shown in Figure 6. Because of the differences in the hotel stars and building area, their energy consumption difference is also relatively significant. Hotel 1 and Hotel 2 are five-star hotels, and their energy consumption exceeds that of Hotel 3 and Hotel 4. Although Hotel 5 is a four-star hotel, its energy consumption is relatively large because of its large building area. In comparison, the energy consumption of the two B&Bs is comparatively small. Therefore, it is imperative to explore the energy-saving potential of high-energy hotel buildings.

Table 1. Detailed parameters of the hotel building.

Hotel or B&B	Total Building Area/m^2 (Excluding Green Area)	Building Floor	Single Floor Area of Building	Hotel Star Index
Hotel	80,000	9	8888.88 m^2	Five-star
Hotel 2	40,000	7	4000~4500 m^2	Five-star
Hotel 3	28,000	4	7000 m^2	Four-star
Hotel 4	10,000	9	1111 m^2	Four-star
Hotel 5	46,800	6	7800 m^2	Four-star
B&B 1	1120	3.5	320 m^2	–
B&B 2	1150	5	230 m^2	–

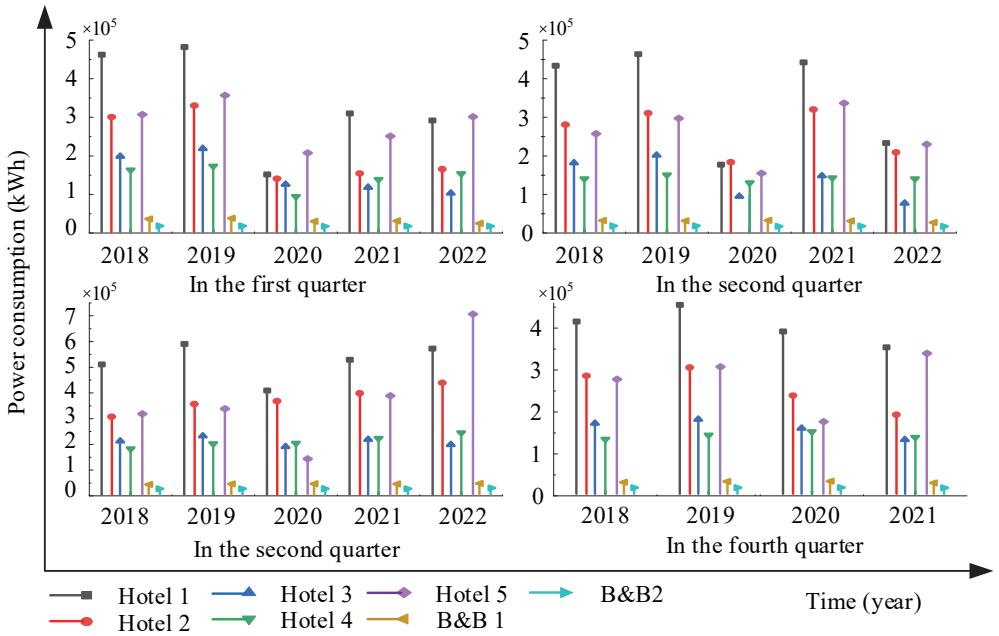

Figure 6. Electricity consumption characteristics of hotel buildings from 2019 to 2021.

Since the outbreak of COVID-19 in 2020, the impact of lockdown policies has significantly changed the energy consumption of different hotels. Compared to the first quarter of 2019, hotels and B&Bs showed a downward trend in energy consumption in the first quarter of 2020. In particular, the year-on-year decrease rates of Hotel 1 and Hotel 2 reached 68.91% and 57.86%, respectively. With the gradual control of the epidemic, many cities began to reopen in May 2020 gradually. The travel rate of people gradually increased, making hotel energy consumption sharply increased in the second quarter of 2020. However, these energy consumptions are still lower than that in the second quarter of 2019, which shows that the hotel industry is still greatly limited by the impact of the COVID-19 epidemic, and the business situation is not optimistic. Under regular epidemic prevention and control, hotels will not gradually recover to the pre-epidemic consumption level until the third quarter of 2021.

Figure 7 shows the typical daily energy consumption curves of these hotels during the holidays from 2018 to 2022. These figures show a downward trend in hotel energy consumption due to the COVID-19 pandemic. At the same time, these data also reflect the characteristics of the hotel business in the post-pandemic era. It can be seen from the figure that under the background of regular epidemic prevention and control, the energy consumption of hotels during the holidays show a significant upward trend, and some hotels have reached the level before the epidemic especially in 2022. This trend is because after a long period of lockdown, people are more willing to go out for recreation during the

holidays under the premise of ensuring safety. In addition, the strong randomness of hotel passengers will also affect the distribution of hotel energy consumption significantly.

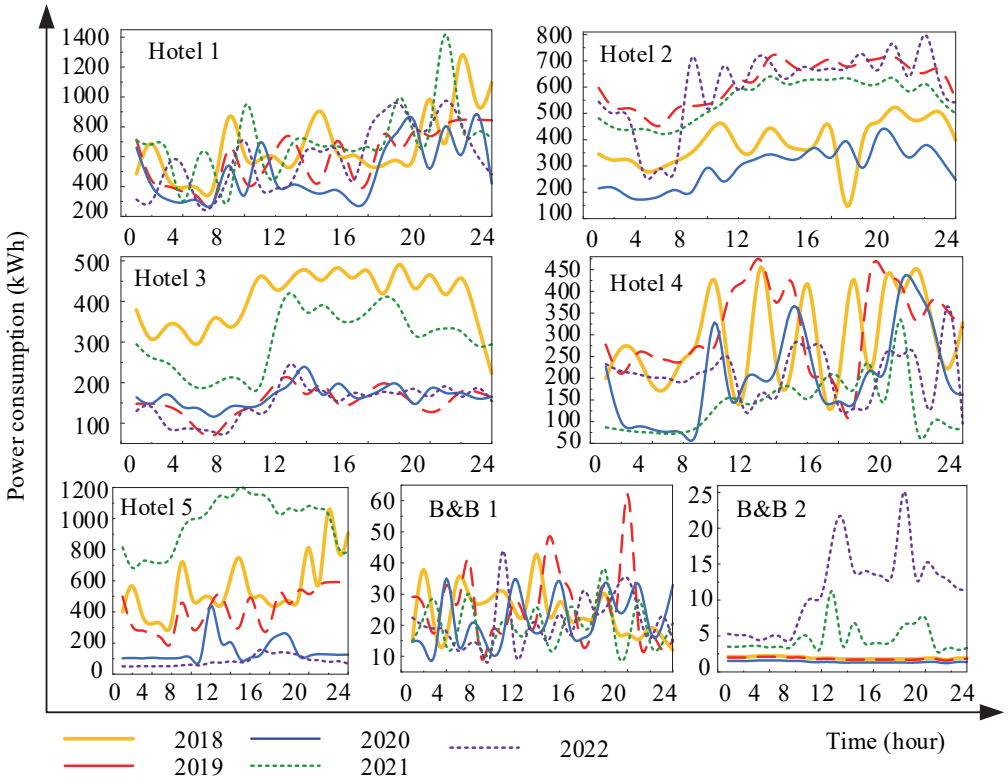

Figure 7. Load distribution characteristics of hotel buildings from 2019 to 2021.

3.1.2. Detailed Energy Consumption Distribution of Hotel during COVID-19

Since the outbreak of COVID-19, the occupancy rate of primary hotels in the country has dropped by more than 80% in the first half of 2020, while many hotels have rates of less than 4%. The annual occupancy level in China in 2020 is close to 50%, down 25.4% year-on-year. Regarding average house prices, the entire year of 2020 fell by 15.2% compared with the same period in 2019, with a gap of 70 yuan in absolute value. In 2021, the epidemic was under control, and the hotel industry was in the recovery stage influenced by the overall recovery of the tourism industry. According to statistics, the average total revenue of hotels in 2021 increased by about 5% compared with 2020, and the average total room revenue increased by about 10%. However, there is still a gap of about 20% compared with 2019.

During the epidemic outbreak, the hotel generally had two operating conditions: (1) The hotel was expropriated by the government and directly involved in the fight against the epidemic. The hotel is basically in full operation. (2) The hotel is basically closed, and there are several long-stay private rooms occasionally, which usually makes it difficult to support the daily operation of the hotel. The study explored the characteristics of hotel energy consumption through the detailed energy consumption distribution of a hotel during the pandemic in February 2020, as shown in Figure 8. At this time, affected by the lockdown policy, the fluctuation range of energy consumption of hotels in an abnormal operation state is very small, basically at a level state.

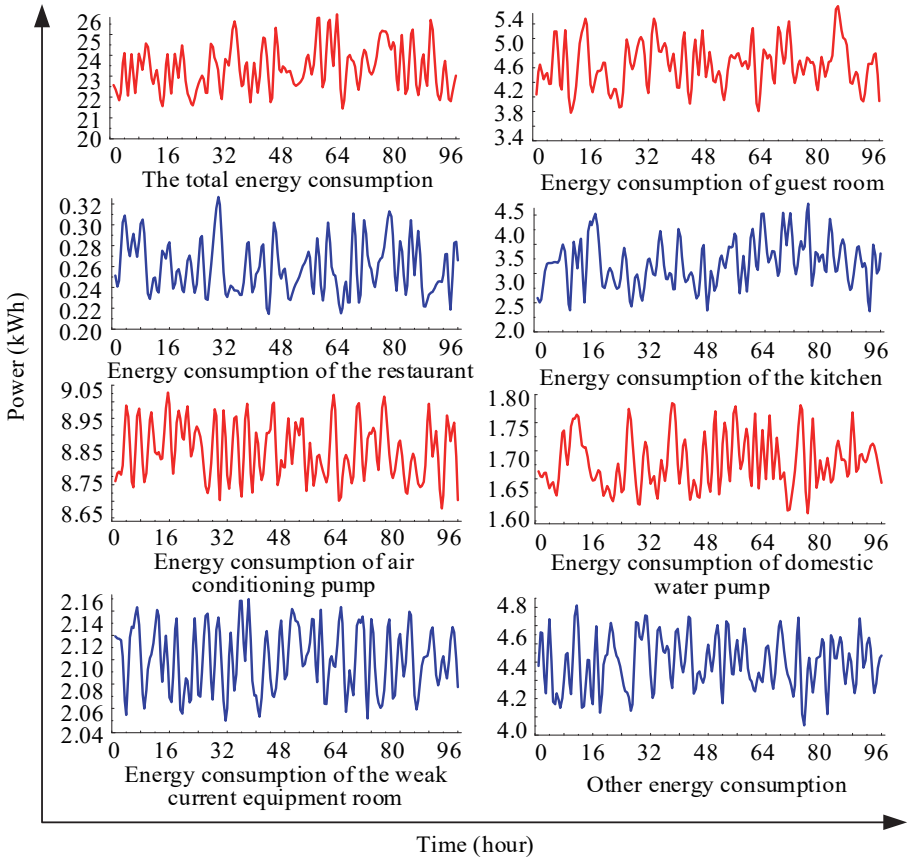

Figure 8. Distribution characteristics of hotel energy consumption during epidemic situation.

First of all, guest rooms are the critical department of the hotel. Their energy consumption also basically presents a horizontal curve. The total daily energy consumption of all guest rooms reaches 484.56 kWh, 46.3% of that in regular operation. This energy consumption mainly comes from small refrigerators, TVs with standby power consumption, emergency lighting, heated toilet seats, etc. Secondly, almost all restaurants in the hotel are closed, and the whole day energy consumption is small, about 25.38 kWh, mainly from emergency lighting and a small amount of refrigeration equipment. In addition, the energy consumption of the hotel kitchen is relatively high, about 64.2% lower than that during regular operation, mainly from refrigeration energy consumption, since hotels need to refrigerate a large amount of food when they are not operating. Therefore, reasonable ECER measures can be effectively formulated through these energy consumption analyses.

In addition, during the epidemic period, the energy consumption of air conditioning in hotels is the most complex. Some hotels will keep the central air conditioner on in order to maintain the specific room demand. In contrast, some hotels will use electric refrigeration, electric heating and other equipment for alternative energy supply to reduce energy consumption. It can be seen from Figure 8 that the power consumption of the air conditioning water pump alone reaches 860.20 kWh. Therefore, its ECER potential is considerable. Moreover, Figure 8 also shows the energy consumption curve of the hotel's domestic water pump and weak machine room. Due to the abnormal operation of the hotel during the COVID-19 epidemic, the staff arranged by the hotel is relatively few. At this time, the weak current machine room of the hotel has become a primary energy consumer.

3.2. Hotel Management and Tourism Economic Characteristics

As shown in Figures 9 and 10, in order to further explore the relationship between hotel management and tourism economy before and after the epidemic, we analyzed the tourism economic development characteristics and hotel management characteristics of

the tourist city during 2012–2020 in detail. From the perspective of the changing trend of tourism income and tourist arrivals, the data from 2012 to 2019 show a growth trend. Its growth rate declined slightly in 2012–2014, but increased yearly in 2015–2017, and slowed down in 2018–2019. In 2020, due to the impact of COVID-19, the city's tourism revenue and total tourist arrivals decreased significantly by 34.2% and 25.9%, respectively.

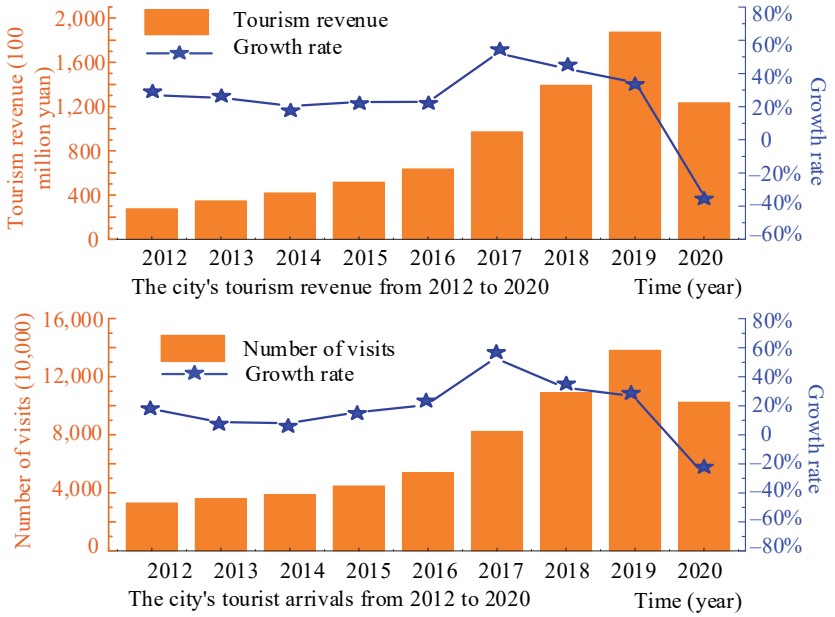

Figure 9. The change trend of the city's tourism economic from 2012 to 2020.

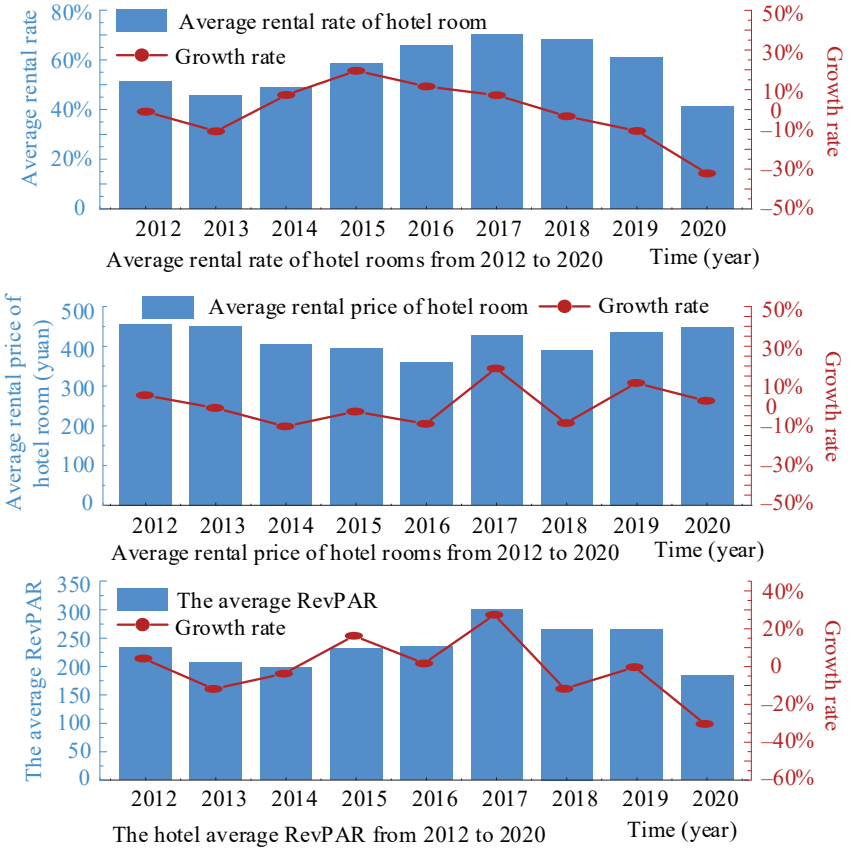

Figure 10. The changing trend of the city's hotel management characteristics from 2012 to 2020.

From the perspective of the hotel's operating characteristics, the hotel room rental rate showed a downward trend in 2012–2013, while it showed an upward trend year-by-year in 2013–2015 with a large increase. Since 2015, the rental rate of hotel rooms has declined. In particular, affected by COVID-19 in 2020, the rental rate of hotel rooms decreased by 32% compared with 2019. At the same time, the average rental price of hotel rooms is also changing. During 2012–2016, the average rental price of hotel rooms fluctuated within a small range and remained basically unchanged, which is consistent with the changes in the tourism economy of the city. From 2017 to 2020, the average rental price of hotel rooms shows an overall upward trend. Compared with 2019, the average rental price of hotel rooms will be less affected by COVID-19 in 2020. In addition, according to the change in Revenue Per Available Room (RevPAR) of the hotel, the average RevPAR from 2012 to 2020 was 235 yuan, of which, the RevPAR showed a slight downward trend from 2012 to 2014, and increased yearly from 2015 to 2017, with a significant overall increase, but fell back in 2018. In 2020, affected by the rental rate decline, RevPAR of hotels dropped by 30.3%. From this point of view, hotel management is positively related to tourism economy, which is of great significance to the energy-saving operation of hotels in the post-epidemic era.

4. Energy-Conversation and Emission-Reduction Measures for Hotels in the Post-Epidemic Era

4.1. Energy-Conservation Strategies in Hotel Buildings

With the gradual control of the COVID-19 epidemic and the gradual opening of lockdown policies, hotel energy consumption in the post-epidemic era will continue to increase with the development of tourism [33]. Therefore, based on the energy consumption analysis above, it is crucial to analyze and explore the ECER strategies of hotel buildings. Compared with other types of commercial buildings, hotel buildings have the following characteristics: (1) the hotel's various facilities and functions are different, and the business hours are also different; (2) the annual average occupancy rate is closely associated with hotel energy consumption (the occupancy rate is higher during holidays and golden weeks); (3) customer consumption is flexible and random [34]. These characteristics makes the hotel energy consumption special. Based on this, under the background of regular epidemic prevention and control, this paper explores the hotel building ECER technology, mainly including building maintenance structure, lighting system, air conditioning system, and operation management.

4.1.1. Energy-Saving of Maintenance Structure

The design of the maintenance structure of the hotel building has great energy-saving potential, in which the energy consumption of doors and windows can reach about 50% of the total energy consumption of the building. Although it is not practical to replace the maintenance structure of existing buildings in large areas, improving the thermal design of buildings in the post-pandemic era can effectively reduce building energy consumption. For instance, the use of reflective glass and double glass can improve the thermal insulation of glass and reduce the cooling load caused by external windows. In addition, by improving the shading facilities, external shading has a more apparent energy-saving effect than internal shading. For instance, the external sunshade system set in the south and west of the area where the sunlight lasts for a long time can significantly reduce the air conditioning load by 16~29%.

4.1.2. Energy-Saving of Lighting System

The lighting system is influenced by equipment power and equipment use time, which has significant energy-saving potential. For example, energy-saving lighting products and intelligent lighting control systems can remarkably reduce the energy consumption of lighting systems without affecting the indoor illumination. Especially in the case of regular epidemic prevention and control, the hotel occupancy rate will be relatively random and flexible according to the changes of the epidemic, which will make the intelligent lighting

system play a huge role in the lighting optimization management of hotel buildings. In addition, the application of multifunctional automatic control systems in lighting systems will bring great ECER potential. For example, in the hotel lobby, elevator lobby, guest room floor corridor and other places, centralized control should be adopted. In contrast, zoning and grouping control measures should be adopted according to the building use conditions and natural lighting conditions, such as the automatic dimming device that regularly reduces the illumination at night.

4.1.3. Energy-Saving of Air Conditioning System

In hotel buildings, the selection of air-conditioning systems is usually based on the heat and cooling loads under the most adverse conditions. However, in actual use, the load will change with the season, weather, occupancy rate, etc. Furthermore, most of the time the actual load is lower than the designed load, resulting in excessive installed capacity [35]. This problem will become even more acute in the post-pandemic era due to the COVID-19 pandemic. In view of this phenomenon, it is imperative to adopt intelligent control technology which can change the state of air conditioning at any time according to the actual demand. Therefore, the corresponding ECER measures adopted in the air conditioning are as follows: (1) reasonable configuration of the capacity and number of cold and heat source equipment; (2) make full use of fresh outdoor air to eliminate indoor load during the transition season; (3) install a frequency converter for the water pump to realize variable flow operation and save transportation energy consumption [36]; (4) design an automatic control system according to the changing rules of personnel to make the indoor temperature and humidity reach the set value [37], thus saving energy and improve indoor comfort.

4.1.4. Energy Saving of Operation Management

The volatility of the COVID-19 pandemic has increased the uncertainty of hotel operations and may bring additional energy losses to hotels. To reduce hotel energy consumption and improve the operation economy, it is critical to explore the optimal management strategy for hotel operations. On the one hand, the hotel is equipped with an extensive public building electricity metering system, which is conducive to the statistics of energy consumption. On the other hand, a reasonable water supply and drainage system should be installed, and advanced water treatment technology should be adopted. For instance, using reclaimed water reuse technology to improve the utilization efficiency of water resources, thus achieving the purpose of saving water and environmental protection. It is worth noting that regular cleaning of dust from air-conditioning vents can significantly reduce system resistance and thus playing an energy-saving role. In addition, during the post-epidemic period, hotels should continue to improve and innovate their management and service systems, so as to achieve energy-saving operation of hotels and enhance customer satisfaction.

4.2. Low Carbon Economy Operation of Hotel Buildings

4.2.1. Optimized Energy Management Promotes Low-Carbon Operation of Hotel Economy

The impact of the coronavirus pandemic has compounded the complexity of hotels' energy consumption. Therefore, an efficient energy operation management method is necessary to achieve the low-carbon economic operation of hotels. On the one hand, by increasing the use of RES in large hotel buildings, such as adding rooftop photovoltaics and solar water heating systems, as hot water supplements for hotel boilers, its application potential can reach about 10%. On the other hand, the hotel should strengthen the introduction of an intelligent energy management system. The hotel energy refinement management system is established by referring to energy consumption data, which can help users find energy-saving space and formulate scientific energy consumption measures, thereby providing strong technical support for the sustainable development of the hotel. By taking the above measures, the average carbon dioxide emission of the hotel can be

reduced by 33~39%, the average water consumption can be reduced by 40%, and the average amount of solid waste can be reduced by 70%.

4.2.2. Low-Carbon and Unique Hotel Design Improve Visitor Occupancy

A hotel design with the low-carbon concept is essential for the long-term development of the construction industry. Unique hotel design also plays a vital role in attracting tourists in the post-epidemic era. Therefore, the low-carbon design of the hotel can be achieved from the following three aspects: (1) Select natural materials and energy-saving construction technology: try to use biological solid dye resources to avoid some harmful substances in the materials, and strengthen the application of RES such as light, wind and geothermal energy. (2) Focus on the attribute and utilization range of construction sources: make a design scheme according to local climate conditions, thus making full use of sunlight to reduce energy consumption during electric energy lighting. (3) Promote the unity of environment and buildings: reduce the environmental pollution of buildings and realize the harmony between residents and nature through using energy-saving materials, rational application of building space and other ways.

4.2.3. Green and High-Quality Hotel Service Guarantees User Satisfaction

According to the sustainable tourism development data, Chinese tourists are more willing to try environmentally friendly accommodation and travel methods to contribute to sustainable tourism development. Table 2 shows the primary reasons that Chinese tourists choose environmentally friendly accommodation and the most popular environmentally friendly accommodation facilities. It can be revealed from the table that achieving the deep integration of the hotel and the local environment and reducing environmental disruption have an important impact on hotel accommodation satisfaction. Moreover, the utilization of solar energy in hotels plays a decisive role in the choice of passenger accommodation. Therefore, accelerating the green, environmentally friendly, high-quality and intelligent hotel service system can effectively improve the hotel injection rate and passenger satisfaction in the post-epidemic era. Moreover, research shows that the employees' productivity is increased by 2~16% on average by creating a healthy and comfortable working environment.

Table 2. Distribution characteristics of reasons for choosing environmentally friendly accommodation.

Reasons for Choosing Environmentally friendly Accommodation		Popular Green and Environmentally friendly Accommodation Facilities	
Reduce damage to local environment	64%	Solar energy	70%
More localized accommodation experience	49%	Recyclable water system	56%
Environmentally friendly accommodation is more conducive to local development	44%	Water saving bathroom	43%
More opportunities to taste local specialties and green organic food	31%	Original organic restaurant or food	48%
Experience new accommodation trends	36%	Indoor goods recycling column	29%

5. Conclusions

With the deepening of green-life concepts, human beings have put forward higher requirements for the sustainable development of society, and the requirements of ECER in all fields of society are more urgent. Therefore, in the context of carbon neutrality, this study discusses in detail the energy-saving operation strategy of hotels considering the impact of COVID-19, which has guiding significance for the operation management of hotel buildings and the development planning of the tourism industry in the post-epidemic period. To reduce economic risk and promote green operations, the study found that, with the constant promotion of regular epidemic prevention and control, energy-saving measures taken by hotels in low-carbon design and resource optimization management can significantly reduce energy consumption by about 16~29% and reduce average carbon

emissions by approximately 33~39%. In addition, reasonable low-carbon consumption modes and intelligent hotel service systems can improve the operating efficiency of the hotel by about 2~16%. The post-epidemic era will make the hotel business continue to grow and become a golden period for implementing ECER strategies in hotel buildings.

In the future, the ECER potential of hotel buildings should be further explored. On the one hand, a refined model of hotel energy consumption should be established, and an advanced hotel energy consumption optimization management system should be developed. On the other hand, the hotel, as a typical large power consumer, explores its participation in power grid demand response, which is of great significance to the reliability and security of power supply stored in the power grid, and also promotes the economy of hotel operation.

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Nomenclature

RES	Renewable Energy Sources
ECER	Energy Conservation and Emission Reduction
HVAC	Heating, Ventilation and Air Conditioning
EUI	Energy Utilization Intensity
B&B	Bed and Breakfast
RevPAR	Revenue Per Available Room

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