

Research on Theory and Application of Energy Consumption and Carbon Emission Benchmark of Star Hotels in China

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Abstract

At present, the Chinese government has listed Carbon Peaks and Carbon Neutrality as one of the eight goals and tasks in 2021 and controlling carbon emissions has become the medium and long-term plan of the national development strategy. Hotel as an important carrier in the process of tourism activities, energy conservation and emission reduction are of great significance for tourism and construction industry to jointly achieve Carbon Peaks, Carbon Neutrality goals. However, the size of emission reduction space should be based on a reasonable carbon emission benchmark for the hotel and accommodation industry. For a long time, the formulation of the benchmark has not been completely unified. In this paper, from the perspective of benchmark research on energy conservation in the field of construction and emission reduction research in tourism accommodation industry, we sort out the relevant literature after 2000, and find out the key and difficult points of benchmark formulation. The research finds that compared with other benchmark studies, the hotel carbon emission baseline evaluation system is more targeted and reasonable for the energy conservation and emission reduction of China's current hotel and accommodation industry. At the same time, the paper compares the evaluation system with ASHRAE energy consumption benchmark model in LEED and the technical path of Guide to The Rational Use of Energy in Star Rated Hotel Buildings, discusses the problems existing in the practical application of the benchmark in China, and puts forward some countermeasures.

Keywords

Hotel; Carbon peak; Benchmark evaluation system; Energy use guide; ASHRAE model.

1. Introduction

According to China's Building Energy Consumption Research Report 2020, 21.7% of the national energy consumption is energy consumption in building operation stage, and the carbon emission in building operation stage accounts for 42.8% of the whole life cycle of buildings, accounting for 21.9% of the national carbon emission, while 37.1% of the total building energy consumption is energy consumption of public buildings such as hotels. On the other hand, the study shows that tourism accounts for 5% - 14% of the human factors leading to global warming [1]. Hotel accommodation has become the second largest carbon emission source of tourism, and the carbon emission of hotel accommodation is still growing (Shi Peihua, 2011, Gössling et al, 2016).

1.1. Definition of Concepts Related to Building Energy Consumption

Because the building will lead to a lot of energy consumption and carbon emissions from the production of building materials required by the construction itself to the construction process, the operation after completion to the Final demolition of the building. The definition of the concept of building energy consumption in this study refers to China's Research Report on

Building Energy consumption: building energy consumption refers to the energy consumption in the operation stage of buildings, including the energy consumption of terminal equipment (such as heating, refrigeration, ventilation, air conditioning and lighting) to maintain the building environment and the energy consumption of various building activities of terminal equipment (such as office working, cooking, etc.).

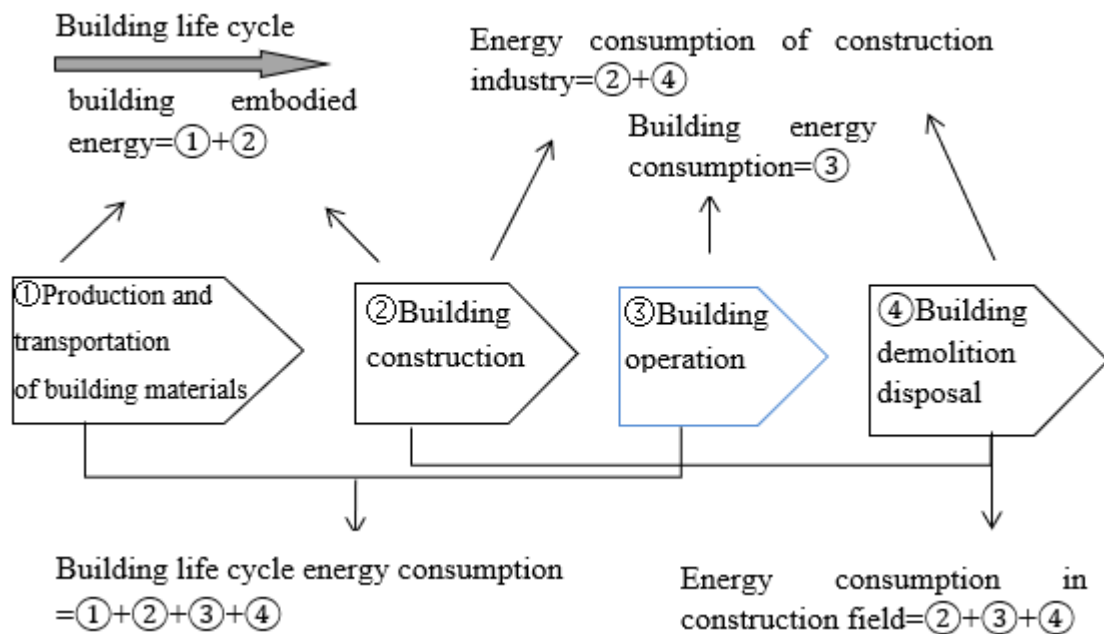


Figure 1. Definition of concepts related to building energy consumption [2]

In this definition, the four stages of the building constitute the whole life cycle of the building. The composition of energy consumption and carbon emission sources in each stage is different, and each stage has a certain space for energy conservation and emission reduction. New hotel buildings can be energy-saving through reasonable design and planning. For existing buildings, after the buildings are put into use, the long-term building operation stage is an important process to test the energy-saving level of building products. On the other hand, taking hotel buildings as an example, due to day and night changes The building energy consumption caused by the alternation of seasons and light and peak seasons is not fixed relative to other stages of the building, and the energy consumption caused by the hotel's 24-hour uninterrupted business and providing a variety of services throughout the year; In order to obtain higher comfort without considering the high energy consumption caused by energy waste, the building energy consumption in the hotel operation stage will be much greater than that in other stages. Therefore, building energy consumption, that is, energy consumption during building operation, will be the focus of this paper.

1.2. Current Situation of Energy Consumption and Carbon Emission of Star Hotels in China

The research shows that the energy consumption and carbon emissions of hotel buildings in China are much higher than those of ordinary residential buildings [2] and far higher than those of hotels in developed countries; Most star hotels in China use centralized air conditioning, and the energy consumption is higher than that of economical and other types of Hotels with split air conditioning; In addition to more diversified room services, star hotels have higher energy consumption and carbon emissions due to more functional partitions such as restaurants, fitness centers, business office areas and washing rooms [3]. Star hotels are the key research object of this paper.

The space for energy conservation and emission reduction during hotel operation depends on the applicability and accuracy of carbon emission benchmark and the measurement of relevant data. In addition to external factors such as social development, hotel area, climate zone and other factors will affect energy consumption and carbon emission during hotel operation. In addition to the diversity of research methods, so far, the technical path of hotel carbon emission benchmark has not been completely unified, and a reasonable carbon emission benchmark model not only provides basis for energy management during hotel operation, Evaluating the energy-saving effect can also evaluate the hotel design.

Therefore, from the perspective of the construction field and tourism and accommodation industry, this paper selects the relevant literature on benchmark, energy consumption and carbon emission research in the academic community since 2000 to sort out, and understand the key and difficult points of the establishment of hotel carbon emission benchmark model. At the same time, the theoretical research and application examples of carbon emission benchmark model in China's star hotel industry are compared.

2. Literature Review

2.1. Benchmark Research Based on Architectural Perspective

The research on building energy consumption benchmark in China is earlier than that of tourism and accommodation industry, and the early research is mainly qualitative.

Zheng Xiaowei (2006) studied the evaluation theory of building energy consumption benchmark earlier and introduced two foreign energy consumption benchmark evaluation tools based on building energy consumption database. He, defined building energy consumption benchmark evaluation as a method of evaluating target building energy consumption similar to building energy consumption characteristics, He believes that the building area and annual energy consumption are the two most important data for the benchmark evaluation of building energy consumption [4]. Cao Yong et al. (2011) evaluated the building energy consumption benchmark from the perspectives of multiple buildings and single buildings, and considered that the building energy consumption benchmark should be applied to the whole life cycle of new buildings and existing buildings from design to operation management [5]. Wei Zheng et al. (2011) studied and analyzed the energy consumption benchmark evaluation method of British public buildings, considered that building energy consumption is affected by building use and operation, and different buildings should have different energy consumption benchmark values, and proposed energy consumption quota benchmark [6]. With the maturity of conceptual theory, some scholars began quantitative research. Liu Gang et al. (2015) believed that public buildings have different energy consumption due to different functions and properties. Based on the existing functional classification, public buildings are divided into five-star, four-star and three-star and below through clustering and rationality analysis. They proposed that different energy consumption index values should be given for the refined classification [7]. Zhu Neng et al. (2015) compared the linear regression method, probability distribution method and quartile method, divided the benchmark into baseline and benchmark. They considered that the baseline is a hypothetical scenario, focusing on the establishment of level standardization. The benchmark evaluation tends to the actual energy consumption level of the target building. In some definitions, the carbon emission baseline and energy consumption baseline are essentially the same, Baselines are measurable or evaluable in existing buildings. In new buildings, the datum line is an ideal model; Single building energy consumption baseline is mostly used to compare their own energy consumption, and multiple building baseline is used to determine the energy consumption level of a building relative to other buildings [8]. By analyzing the current situation of carbon trading in public buildings in Beijing and Shanghai, Yang Sihui and Liu Jing

(2020) believe that the division of direct carbon emission and indirect carbon emission will affect the statistical results of energy consumption, and the carbon emission intensity per unit area of high-energy hotels may be lower than that of low-energy hotels [9].

Most of the above studies do not take hotel buildings as the exact research object, or when it comes to hotels, they are only classified into public buildings for analysis, and hotel energy consumption is different from other public buildings. Therefore, the energy consumption benchmark in the construction field cannot be completely copied and applied to the star hotel industry. However, these studies have made us have a certain understanding of the difficulties and key points of benchmark establishment, that is, the establishment of benchmark should pay attention to both the horizontal change of time dimension and the vertical comparison of space caused by functional zoning. If we want to study the formulation method of hotel benchmark, we can not be separated from the influence of the characteristics of hotel buildings and the environment, Benchmark is not a fixed theoretical value, but a process of quantifying by changing prediction model or evaluation system composed of multiple indicators.

2.2. Research on Energy Consumption and Carbon Emission of Star Hotels from the Perspective of Tourism and Accommodation Industry in China

From the literature, the research on hotel energy conservation and emission reduction in China mainly focuses on the analysis of the current situation of energy consumption of regional hotels, the research on the influencing factors of carbon emission, the overall measurement of energy consumption and carbon emission, and less on the carbon emission benchmark of star hotels.

Huang Jiangang (2006) proposed earlier that energy management should be taken as the development strategy of hotels [10]. Research shows that there is indeed a certain space for energy conservation and emission reduction in China's star hotels. Happy et al. (2007) established a hotel economy energy environment system model and analyzed the data of eight domestic hotels. It is found that there is a large gap in energy consumption and output among different hotels [11]. Huang Qi et al. (2014) found through follow-up investigation that the hotel produces the most carbon emissions is electricity, and the hotel's HVAC and air conditioning account for the highest comprehensive energy consumption. Using the decomposition analysis method, they constructed a comprehensive energy consumption and carbon emission evaluation model suitable for the characteristics of the hotel accommodation industry, which confirmed that all star hotels have the potential of energy conservation and emission reduction [12]. Gu Wen et al. (2014) found that hotels generally have energy consumption problems in building body, equipment and facilities and hotel operation management by summarizing and sorting out the energy consumption status and energy consumption characteristics of hotel buildings in China [3]. Zhang Jixin and Zheng Xiaowei (2009) established a calculation model for the actual energy consumption of Yangzi hotel by using the building energy consumption simulation calculation software, simulated the hotel operation and energy use, carried out energy-saving transformation, and achieved the goal of 50% energy saving [13].

Some scholars have conducted regional research and Analysis on the current situation and influencing factors of hotel carbon emission. Yu Xiaoping and Fu Xiangzhao (2007) investigated and analyzed the energy consumption of 12 star hotels in Chongqing and put forward energy-saving transformation approaches for existing hotels [14]; Wei Wei et al. (2010) took star hotels in Guangdong Province as an example, using factor analysis method and empirical research on the influencing factors of promoting energy conservation and emission reduction in hotel accommodation industry in China [15]; Li Peng et al. (2010) selected 6 four-star hotels in Kunming and constructed the carbon footprint model of hotel accommodation products [16]; Qi Xiaolin et al. (2011) compared the actual energy consumption values of 12 large hotels in Xi'an, analyzed the existing energy management problems and put forward improvement suggestions [17]; Tao Yuguo and Huang Zhenfang (2013) constructed a carbon emission

measurement system for the accommodation industry based on the hotel industry in the Yangtze River Delta [18]; Shen Yang et al. (2017) calculated the carbon emissions of three different star hotels in Ningbo and analyzed the low-carbon indicators. It was found that among the carbon emissions per unit building area, five-star hotels are the smallest, but the carbon emissions per unit passenger and unit rental days are the largest [19]. The luxury of hotel facilities is an important factor. In addition, there are some differences in energy consumption and carbon emissions between Mountain hotels and hotels in plain areas. Yao Lizhong et al. (2020) took Huangshan Xihai Hotel, a four-star Mountain Hotel, as an example, and found that the per capita energy consumption of tourists per night is lower than the average energy consumption of Chinese star hotels. The reason is that the high altitude of Mountain hotels leads to the reduction of air conditioning and energy consumption, In addition, the hydropower energy consumption of the housekeeping department and the catering department is less than that of the plain Hotel, but the energy consumption of other functional areas such as lighting and public utilities accounts for a large proportion, and the energy consumption is positively correlated with carbon emission [20].

Other scholars have studied the carbon emission of the national hotel industry according to different indicators. Shi Peihua et al. Calculated the annual carbon emission of national star hotels through the number of hotels, number of beds, number of rooms, occupancy rate and energy consumption in each year, and found that the carbon emission of national star hotels reached 15.36 MT in 2008 [21]. At the same time, carbon emissions are closely related to urban development. Hu Linlin et al. (2015) found that urban tourism development space and potential can be known from the comprehensive total carbon and per capita of regions and cities, and the ratio of carbon emissions to GDP can reflect the dependence of regional or urban economy on tourism [22].

Summarizing the above research, it can be found that scholars have done a lot of research on energy consumption and carbon emission of China's hotel accommodation industry, from qualitative to quantitative, from overall carbon emission of the hotel industry to Regional Hotel carbon emission, from analysis of influencing factors to putting forward scientific countermeasures, and the research direction of hotel carbon emission is more diversified, The main problems of previous studies are: there are more studies on macro energy consumption and carbon emission of hotel accommodation industry, and less theoretical research on benchmark; There are many studies on the overall energy consumption and carbon emission of hotels, but few studies on the energy consumption of hotel functional zoning and comparable unit building energy consumption; From the perspective of government and other regulatory departments, there are more problems, but less from the perspective of hotel building owners and managers; Although there are studies on carbon emission benchmarks, there is neither unity nor comparison between the construction methods of benchmark models. A scientific and reasonable benchmark should not only accurately reflect the energy-saving and carbon reduction space of the hotel and reflect the environmental benefits, but also quantify the economic benefits and enable the hotel operators and managers to receive data feedback. Moreover, the hotel carbon emission benchmark model should take into account the following factors at the same time: first, there are certain differences in hotel energy consumption and carbon emission in different regions, and the impact of factors such as the climate and local economic development level of the hotel on the benchmark model. 2 There are differences in energy consumption and carbon emissions among hotels of different sizes and grades. The benchmark assessment should take into account the influencing factors such as the difference of hotel area, hotel type or service capacity. 3 Direct carbon emission and indirect carbon emission shall be defined in the measurement of hotel energy consumption and carbon emission. 4 There are differences in energy consumption and carbon emission in different

functional zones. The energy consumption per unit area of the hotel can not reflect the overall energy consumption level of the hotel, and comparable unit indicators should be introduced.

3. Benchmark Study on Hotel Carbon Emission in China

The benchmark model of hotel operating energy consumption and carbon emission needs strong data support. The energy consumption in hotel operation in China has changed from extensive high energy consumption and carbon emission dominated by fossil energy to high energy consumption caused by the pursuit of higher service level, more service functions and larger building space. The early benchmark model can not fully meet the needs of energy conservation and emission reduction of modern hotels.

By combing the recent literature research, it is found that the carbon emission baseline evaluation system of hotels in China constructed by Huang Qi, Kang Jiancheng, Zhang Jianye and other scholars has important reference value. In the study, the direct carbon emission and indirect carbon emission of hotels in China are clearly defined: the greenhouse gas generated by fossil fuels such as natural gas, gasoline and diesel is taken as the direct carbon emission of hotels, and the greenhouse gas emission caused by the use of purchased power and heat is counted as indirect carbon emission (vehicles owned or leased by hotels, And the comprehensive energy consumption of the building leased to the outside and independent of the lessee is not included). Then, the comprehensive energy consumption evaluation model, direct carbon emission model and indirect carbon emission model are constructed by decomposition analysis method, and the error is corrected. Finally, based on the above hotel energy consumption evaluation model, the main evaluation indicators (Hotel comprehensive energy consumption, hotel comparable unit building comprehensive energy consumption), input-output energy consumption evaluation indicators (Hotel 10000 yuan equivalent energy consumption, hotel unit building annual energy consumption) [23], industrial characteristic evaluation indicators (Hotel 10000 yuan unit building annual energy consumption, hotel guest room annual energy consumption The annual energy consumption of hotel unit building electricity, the annual energy consumption of hotel unit building fuel, the energy consumption of hotel restaurant Entertainment unit building area and the energy consumption ratio of hotel entertainment business building area) are used as the evaluation indicators of carbon emission benchmark. The carbon emission baseline (MRV) and carbon emission baseline evaluation system are studied and constructed. The sample subjects are mainly star hotels in the Yangtze River Delta, Through field investigation and collecting the energy consumption data of the target hotel for 1-6 years, the carbon emission benchmark model is verified on the spot, and the carbon emission benchmark data of different types and sizes of hotels are obtained [23]. The evaluation indicators are shown in Figure 2.

From the technical path of the evaluation system, considering the influence of hotel area, direct carbon emission and indirect carbon emission, the comprehensive energy consumption and unit energy consumption of each functional zone are taken as the primary indicators, so that the internal energy management of the hotel can be compared, so that the hotel can understand its own energy consumption level in the industry, and the space for energy conservation and emission reduction can be reflected more intuitively, It is helpful for hotel enterprises to put forward corresponding solutions to different problems, realize energy conservation and emission reduction and cost control, and facilitate the management of relevant departments such as the government, which can not only create environmental benefits for the society, but also quantify the economic benefits of the hotel.

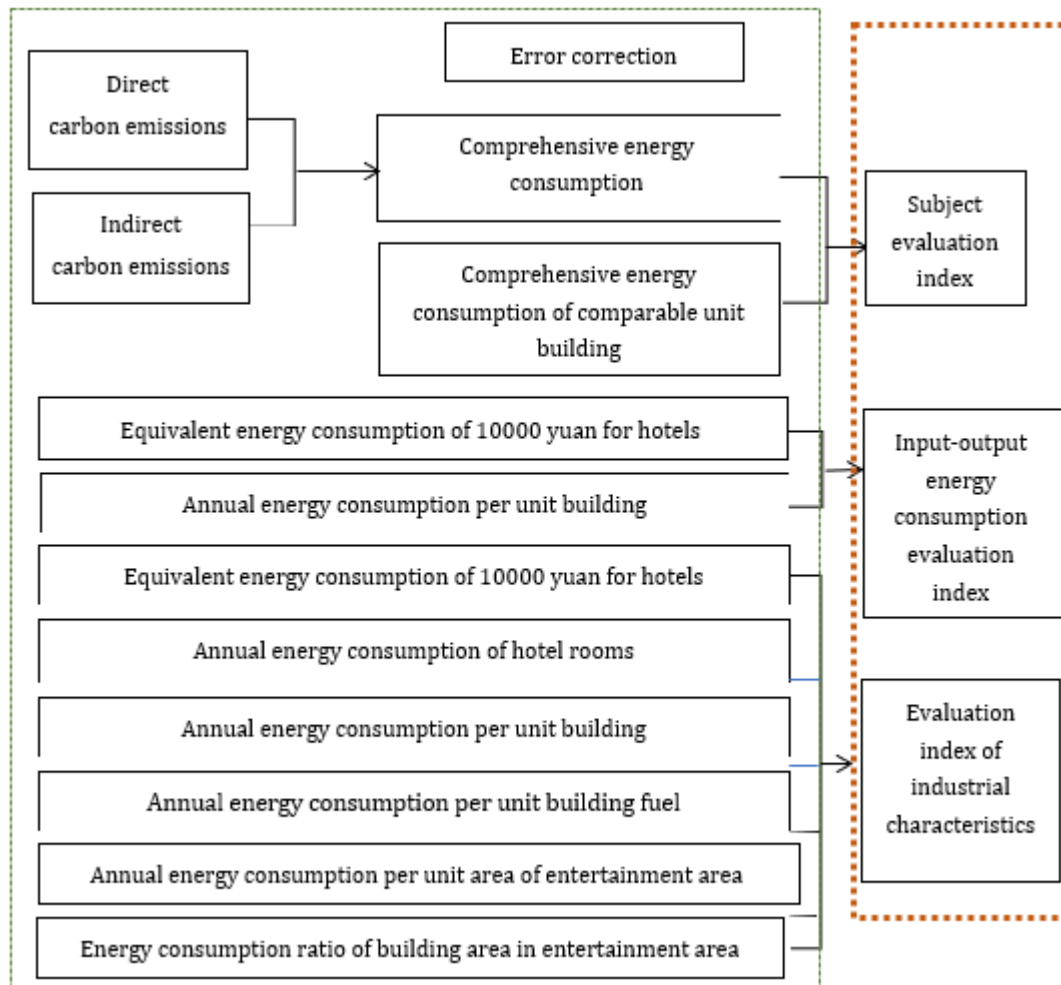


Figure 2. Assessment indicators of carbon emission baseline of hotels

4. Application Status of Energy Consumption and Carbon Emission Benchmark in China

At present, many countries in the world have developed benchmark evaluation tools for building energy consumption. Hotels can fill in building information online, such as regional location, building type, building area, running time, energy consumption data, etc. the tool will automatically analyze through the internal set mathematical model, and then calculate the building energy consumption, and compare with the energy consumption of similar buildings in the database. Among these tools, Energy Star, Cal-Arch are the most representative [5]. Data show that more than 30000 commercial buildings in the United States were evaluated by "Energy Star" as early as 2010, and more than 3200 of them were certified [24-25]. The powerful support behind such a mature tool comes from the relatively complete databases CBECS [26] (commercial building energy consumption survey) and CEUS (California commercial end use survey). At present, it is difficult to obtain hotel related building information in China, and the corresponding benchmark evaluation tools have not been developed. The application of hotel energy consumption and carbon emission benchmark in China is mainly seen in the green building evaluation system [5], For example, ASHRAE energy consumption benchmark model mentioned in American Energy and Environmental Design Pioneer (LEED) in Building Design and Construction Reference Guide and China's Star Hotel Building Reasonable Energy Use Guide. LEED certification system is established and implemented by the Green Building Council of the United States. Its full name is leadership in energy & environmental design building rating system. It is considered as a relatively perfect

Table 1. Comparison of ASHRAE energy consumption benchmark model, energy guide and carbon emission benchmark evaluation system

	ASHRAE energy consumption benchmark model	Guidelines	Carbon emission benchmark assessment system
Technical standard or method basis	ASHRAE 90.1	China's Green Tourism Hotel, General Principles of Comprehensive Energy Consumption Calculation and so on	IPCC recommended international general method, decomposition analysis method
main parameter	Envelope, air conditioning, lighting, climate, other equipment parameters and other energy consumption values	Hotel area, energy consumption data, room occupancy rate and suite number, other functional area data, etc.	Direct and indirect energy consumption data, hotel area, occupancy rate and number of rooms, other functional area data, annual revenue of the hotel, etc.
Sources of important data and difficulty of collection	Hotel equipment and facilities rating data, equipment monitoring, data collection is less difficult	Measurement device, full-time personnel record data, data collection is less difficult	Relevant departments of the hotel energy bill documents and effective processing, data collection time 1-6 years
Benchmark focus	Based on customer comfort and energy strategic needs of hotel owners	Reasonable energy use of buildings	The reasonable use of building energy is based on the hotel's own economic benefits and reflects the hotel's energy consumption level in the industry
Technology path	Through the model, under the conditions of the corresponding climate zone, simply simulate the energy consumption value obtained from the rated power and operating parameters under the ideal state of the equipment, and compare it with the actual energy consumption as the reference value	The energy consumption calculated by the model is compared with the reasonable value and advanced value	The energy consumption obtained by the model is compared with the reasonable value and advanced value, and the energy consumption of different zones in the hotel is compared horizontally and economically
advantage	The model is mature, the database resources are rich, and the new building is different from the existing building	The comprehensive energy consumption and comparable unit energy consumption are clearly divided, which can directly reflect the distribution of hotel energy consumption The direct and indirect carbon emissions are not clear. To consider climate factors, hotels of the same grade are easy to form a standard of "one size fits all", which does not directly reflect the hotel energy consumption input-output and other economic indicators	The comprehensive energy consumption and comparable unit energy consumption are clearly divided, and the direct and indirect carbon emissions are clear, which can directly reflect the hotel energy input-output and other economic indicators
shortcoming	Focusing on high comfort leads hotels to pursue low energy consumption but high cost		It is suitable for hotels in East China and similar climate regions where the samples are located. There is no data feedback for hotels of other climate types

and influential evaluation standard. China has become one of the countries with the largest number of LEED registrations, Controlling the actual energy consumption of hotels within LEED

benchmark is the basis for hotel enterprises to obtain relevant certification. The Guidelines for The Rational Use of Energy in Star Rated Hotel Buildings (hereinafter referred to as the Guidelines) was first issued by Shanghai Municipal Bureau of market supervision in 2011 to promote energy conservation and consumption reduction in hotel buildings, and revised in 2019. This paper compares and analyzes the energy consumption benchmark in LEED, the energy use guide and the technical path of hotel carbon emission benchmark evaluation system proposed by Huang Qi et al. (Table 1).

ASHRAE energy consumption benchmark model is established by referring to the method of appendix g of ASHRAE 90.1 (for example, ASHRAE 90.1-2010 version is adopted in leedv4.0). The parameters of envelope, lighting, air conditioning system and other equipment in the model will be selected according to the climate area of the target hotel. This climate area is ASHRAE's division of all parts of the world. In addition, it will also be selected according to the mandatory and provisions of each chapter in the system certification; The main data in China's energy consumption guide and carbon emission benchmark are the overall and local energy consumption of hotels, which does not distinguish between functional performance consumption such as lighting and air conditioning, that is, the energy consumption of lighting and air conditioning does not need to be measured separately. It reflects that ASHRAE pays more attention to the impact of architectural design on energy consumption during hotel operation from the perspective of the whole life cycle of the hotel, and the latter two pay more attention to the impact of real-time energy consumption and carbon emission. ASHRAE compares the data calculated by the model with the energy consumption of buildings with similar climate and similar functions in its database and calculates the energy consumption value with reference to the rated power of equipment. The three data are compared at the same time, depending on whether the hotel is a new building or an existing building. Both the carbon emission benchmark evaluation system and the Energy Consumption Guide compare the model calculation data with the specified reasonable and advanced values. At the same time, the input-output and industry characteristic evaluation set in the carbon emission benchmark evaluation system enable the hotel to consider social and economic benefits at the same time.

5. Conclusion and Prospect

5.1. Conclusion

The hotel accommodation industry should do a good job in energy conservation and emission reduction, which has both environmental and economic benefits. From a macro point of view, a reasonable benchmark setting will help the construction industry and tourism achieve carbon peak. From the micro perspective, the energy consumption of the hotel can be reduced, the cost can be saved, and the market competitiveness can be improved. The carbon emission benchmark enables the hotel to understand its own energy conservation and emission reduction space and has a basis for taking actions related to energy management. At present, China has more research on energy consumption and carbon emission, but less research on hotel benchmark. Due to different statistical caliber and difficult data acquisition, China has not fully formed a unified standard for the application of energy consumption and carbon emission benchmark. Through the above research and analysis, a reasonable energy consumption and carbon emission benchmark of hotel accommodation industry should comprehensively consider climate, hotel type. The impact of direct and indirect carbon emissions should also take into account the input-output economic indicators and industry characteristic indicators, which can not only measure the environmental benefits of the hotel, but also reflect the economic benefits, mobilize the enthusiasm of energy conservation and carbon reduction of the hotel accommodation industry, and accelerate the hotel accommodation industry to achieve carbon peak.

5.2. Outlook

Based on the above research and analysis, China's benchmark system can be improved from the following perspectives in the future research and application of hotel accommodation industry:

First, improve the energy consumption database of China's hotel accommodation industry. The more perfect the database, the stronger the feasibility of the benchmark. As mentioned earlier, energy star and cal arch benchmark evaluation tools. At present, it is known that Shanghai has established its own building energy consumption database, including 214 hotel buildings in 2019, which is being further improved. Other regions can learn from it. The climate, hotel type and level of the region should be counted as influencing elements. In the future application of receipts, the "one size fits all" of the benchmark line can be avoided. For example, the benchmark of Mountain hotels and plain hotels at the same latitude, Western hotels and similar hotels in the East should have different references.

Second, the benchmark should set evaluation indicators that can reflect the environmental and economic benefits of the hotel. Ignoring environmental indicators is bound to reduce the intensity of energy conservation and emission reduction of hotels, while ignoring economic indicators can not drive the enthusiasm of energy conservation and emission reduction of hotel accommodation industry.

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