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Energy Evaluation Method and Index Analysis of Hospital Building

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ABSTRACT

Energy analysis and energy evaluation are the important basis of efficiency management of hospital building. The purpose of this paper is to summarize the scientific and applicability of the evaluation methods and indicators of hospital energy consumption in China. Based on the analysis of energy consumption characteristics of different types of hospitals, the simple normalization method and multiple regression model were used to evaluate the building energy consumption of hospitals, and the conclusions of the two were compared. Based on the data analysis of 30 sample hospitals in Shanghai, this paper analyzes the defects in the evaluation and classification method of Chinese hospital buildings and the quota energy consumption index. This study found that at the present stage, the classification of hospital energy consumption evaluation in China is not clear, and the evaluation conclusions obtained from different indicators are inconsistent. On this basis, this paper puts forward the development needs of hospital energy consumption analysis and energy saving evaluation in the classification of hospital types, selection of evaluation indexes and dynamic evaluation methods, in order to solve the above problems effectively.

Keywords: Hospital, Building Energy consumption, Energy Evaluation Benchmarking, Building Energy Indexes

NONMENCLATURE

Abbreviations	
BEI	Building Energy Indexes
EUI	Energy Unit intensity
EPB	Energy Per Bed
EPP	Energy Per Patient
GH	General hospitals
SH	Specialized hospitals
TCMH	Traditional Chinese medicine hospitals

1. INTRODUCTION

The construction sector is one of the three major energy consumption sectors in China, accounting for about 21.11% of the national energy. Among them, hospital, which have high occupancy rate and strict indoor environment requirements, become a main kind of high energy building in public buildings. In China, the area of hospital building only accounts for 2.8% of the total area of public buildings, but the energy consumption accounts for 6.2% of the total energy of public buildings. According to Tsinghua University China Building Energy Use 2018, Energy Unit Intensity (EUI) of hospital is 1.0 to 2.3 times that of general public buildings.

Energy analysis and energy evaluation are the important basis of efficiency management of hospital. In the evaluation of energy-saving effect, the Building Energy Indexes (BEI) of hospital energy is controversial. Energy Unit intensity (EUI), Energy Per Bed (EPB), and Energy Per Patient (EPP) are common indicators for evaluating hospital energy consumption. In addition, some studies put forward more special indicators such as Energy Unit Medical Volume, Energy per Ten thousand income, etc. The starting points of above indicators are different, and each index is interpretable. But neither of them was able to evaluate hospital energy consumption comprehensively. The following will focus on the defects of the BEI and energy evaluation methods combining the actual hospital data to deeply analyze the current of hospital energy using and the building evaluation.

2. LITERATURE REVIEW

The problem of high energy consumption in hospital exists all over the world. The increase in medical demand and the greater comfort demand by patients have led to

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the renovation and expansion of existing hospitals and the construction of new hospitals. All of this led to the consideration on the selection of Building Energy Indexes (BEI) of hospital energy consumption. EUI has been considered inadequate to evaluate the increasing hospitals energy consumption due to medical development and human needs. Therefore, the research on the index of hospital building energy consumption has been carried out all over the world. A study in German[1-3] found EPB was more suitable for evaluating hospital energy consumption. A Spain study got the same concluded with the German one, and furthermore it made 300 beds as the dividing line standardizing electricity, natural gas, diesel and other energy sources for the bed average energy consumption. A Korean studyalso mentioned EPB was the most suitable reference for quantifying hospital energy consumption. In addition, some studies have proposed that there is a high correlation between the number of annual discharges, number of emergency operations and number of hospitalizations[4] medical activities as evaluation criteria[5,6] and hospital energy utilization.

In addition to the simple normalization of single index evaluation method mentioned in the above research, some studies believed that floor area, number of beds, number of patients and working hours will all affect the energy consumption of hospital buildings in the meantime. They proposed multiple regression method to accomplish this operation. Among them, the most famous one is Energy Star, a benchmark evaluation tool for building Energy consumption in the United States, which uses the powerful building database in the United States to establish a regression model for hospital buildings. Liu Chaoyang[7] established a multiple linear regression equation by using hospital data in Wuhan, China, with energy consumption as the dependent variable and floor area and number of inpatient beds as independent variables. Wei Zheng[8] adopted the stepwise regression method to establish the regression equation by using 45 hospitals data, with parameters as floor area, the bed number, the employee number and the surgeries number.

Although extensive evaluation has been done on evaluation method and energy consumption index of hospital building separately, However, there is no comparison and detailed description of the advantages and disadvantages of each evaluation method. The purpose of this study is to compare the advantages and disadvantages of the two methods on the basis of in-depth analysis of hospital energy consumption characteristics and influencing factors, and put forward solutions accordingly.

3. METHODS AND METRICS

3.1 Simple normalization

Simple normalization approach relies on relative energy efficiency indicators calculated simply, namely the ratio of a single input to output. Hospital energy efficiency indicators are usually obtained by simply standardizing energy use based on floor area, hours of operation or number of people using energy. However, before normalization, it is necessary to classify the types of hospitals in order to provide more accurate value.

3.2 Regression model

The use of regression model to calculate the reference building energy consumption belongs to the grey box method, which not completely relies on physical rules but takes data-driven as the main method and is supplemented by theoretical guidance. It's a rule of thumb. This method is based on a complete database of energy consumption. The quality and quantity of energy consumption of each building in database are directly related to the accuracy of the model.

This study definition Energy consumption ratio as:

$$R = \frac{E_j}{E_{jR}}$$

where coefficients R represent the dependent variable energy consumption ratio while Ej represents actual the energy consumption of hospital and EjR represents the energy consumption of hospital computed by regression model standardizes.

According to this formula, if the calculated energy consumption ratio of a hospital is less than 1, the energy efficiency level of the hospital can be considered higher than that of general buildings. The lower the energy efficiency ratio, the higher the energy efficiency level. According to the ranking of energy consumption ratio R,

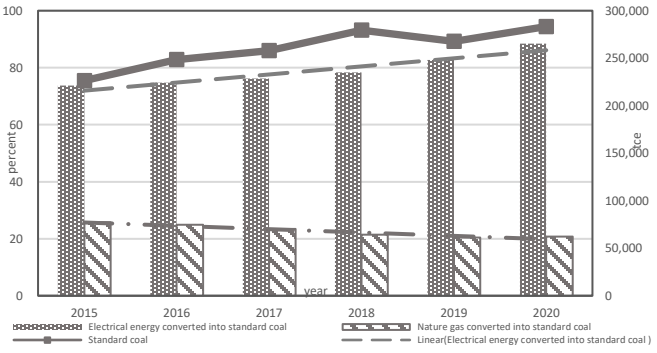

Fig 1. Energy consumption structure of sample hospital in the years 2015 to 2020.

the top 25% are high energy efficiency hospitals and the bottom 25% are low energy efficiency hospitals.

4. BUILDING ENERGY CONSUMPTION ANALYSIS

4.1 Basic information of sample hospitals

In this paper, 30 Class Ⅲ Grade Ⅰ hospitals in Shanghai were selected as the investigation objects, including 11 general hospitals (GH), 15 specialized hospitals (SH) and 4 traditional Chinese medicine hospitals (TCMH). The floor area ranges from 1900 m^2 to 368,800 m^2, with average floor area of 140,100 m^2. Total 72 million patients annually visited the outpatient department; There are 35,968 beds. From 2015 to 2020, the total construction area of hospitals in Shanghai increased by 10.8%, the outpatient increased by 6.7%, and the number of beds increased by 4.8%.

4.2 Study of Energy structure of sample hospitals

Electric energy and natural gas have been the main energy sources of sample hospitals. From 2015 to 2020, the total energy consumption of Shanghai hospitals showed a trend of increasing year by year. Primary energy has increased by 25% in the past five years. The change of hospital energy consumption structure in Shanghai is shown in Figure 1, with the proportion of electricity consumption changing from 73.8% to 88.4%, natural gas decreased from 25.8% to 20.7%, gasoline increased from 0.4% to 0.24%.

4.3 Study of Energy Consumption per hospital type

In general, the Energy Unit intensity (EUI) of 30 hospitals in 2020 was 66 kgce/m^2 which the Energy Per Patient (EPP) and the Energy Per Bed (EPB) were respectively 442.66 kgce/ m^2 and 8462.56 kgce/ m^2. As showed in Figure 2, the EUI of the hospitals involved in this study increased by 4.7% in the last five years. But from 2018 to 2020, except for SH, the EUI of GH and TCMH showed a decreasing trend which accounted for the high requirements for building energy conservation in recent years in China is also success in hospital energy conservation.

In addition, the EPP and the EPB of the hospitals involved in this study increased by 5.3% and 13.8% respectively in the past five years. As Figure 3 and Figure 4 illustrated, the EPP and EPB in general hospitals showed an increasing trend. In specialized hospitals, the EPB maintained a steady growth trend while the EPP showed a brief downward trend in 2018.

4.4 Study of Correlation analysis

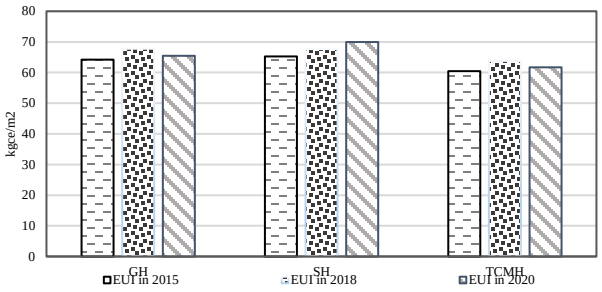

Fig 2. Relationship of EUI of sample hospitals in the years 2015,2018,2020.

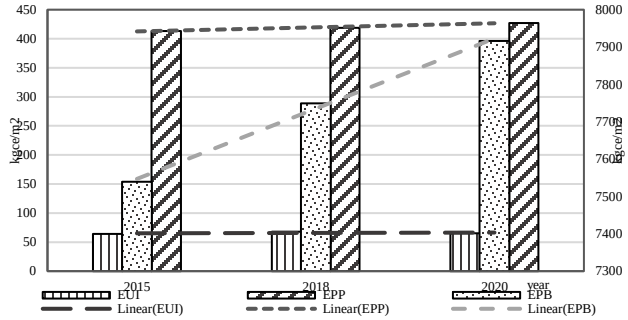

Fig 3 Relationship of EUI\EPP\EPB in GH in the years 2015,2018,2020.

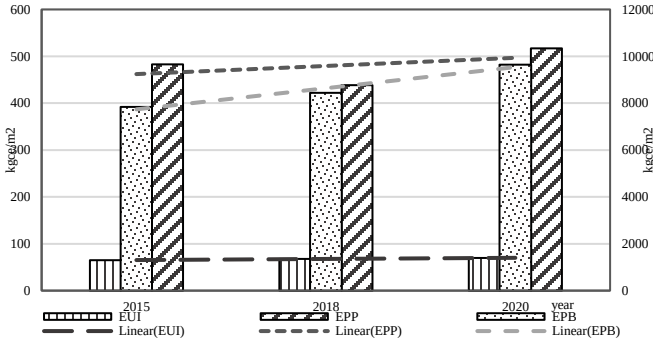

Fig 4 Relationship of EUI\EPP\EPB in SH in the years 2015,2018,2020.

Numerous studies have found that the annual energy consumption of hospital is strongly correlated with floor area, number of outpatients and number of beds. However, few studies have compared the differences between different types of hospitals under the influence of the above factors.

The Pearson coefficient results of the sample hospitals in this study are shown in Table1. The analysis studied the relationship between the building area, the

	Floor Area	Number of outpatients	Number of Bed
Pearson	0.970	0.816	0.869
$p-value$	0.000*	0.528	0.249

Table 1 Results for Correlation Coefficient of Pearson for the annual energy consumption.

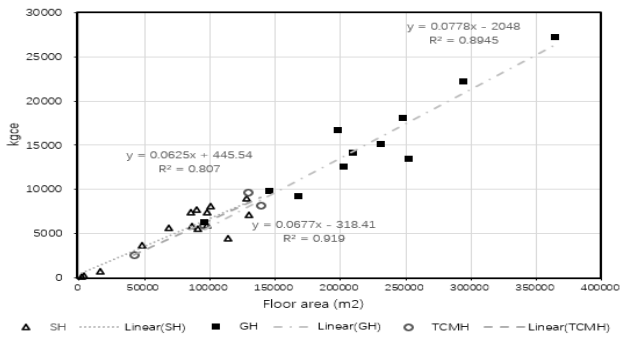

Fig 5 Relationship between the annual energy consumption and floor area of sample hospital..

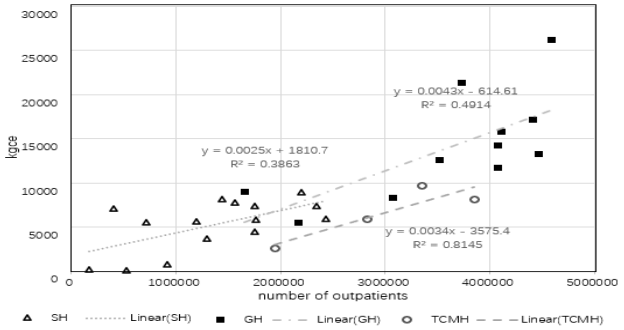

Fig 6 Relationship between the annual energy consumption and number of outpatients of sample hospitals.

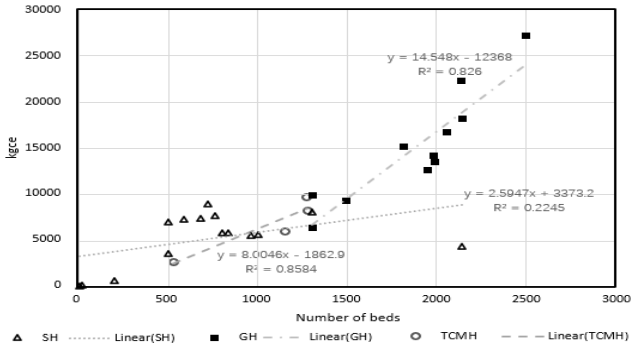

Fig 7 Relationship between the annual energy consumption and number of beds of sample hospital.

number of visits, the number of beds and the average annual energy consumption of the hospital. The results obtained from the statistical ANOVA of the sample hospitals are presented to determine whether any of the differences between the means were statistically significant.

Fig. 5 illustrated a high linear correlation between the annual energy consumption and floor area of per sample hospitals (RGH = 0.8945, RSH = 0.807, RTCMH = 0.919). Fig. 6 showed a weak correlation in GHs and SHs shows (R_2<0.5, R_{GH} = 0.49, R_{SH} = 0.38) while the correlation of TCMHs is highly linear dependence (R_{TCMH} = 0.81). Fig.7 reflected a strong linear correlation between building energy consumption and the number of beds in different types of hospitals (R_{GH} = 0.83, R_{SH} = 0.61, R_{TCMH} = 0.86). However, from the formula coefficient, the increase of unit bed number brings different changes in energy consumption in different types of hospitals. Compared with GHs and TCMHs, the increase of unit bed number in SHs brings less increase in energy consumption.

5. RESULTS OF ENERGY CONSUMPTION EVALUATION

5.1 Study of Correlation analysis

This study takes the Yangtze River Delta of China as the study area to study the energy consumption evaluation benchmarking of the sample hospitals. China's Yangtze River Delta includes the contiguous provinces of Shanghai, Zhejiang and Jiangsu. Table 2 listed the differences of hospital energy consumption benchmarking in the three provinces, from the differences in first-level classification, second-level classification, evaluation index, quota value to the time of promulgation.

Since all sample hospitals are Class Ⅲ hospitals, only Class Ⅲ hospitals reference value in Zhejiang and Jiangsu are taken as an example to analyze the differences between the energy consumption benchmarking of hospitals in the three provinces. The EUI of per sample hospital ranged from 50.8 to 75.7 kgce/(m^2·a) for GHs, 39.9 to 92.6 kgce/(m^2·a) for SHs and 57.8 to 69.7 kgce/(m^2·a) for TCMHs, respectively.

Based on Shanghai hospital energy benchmarking, the sample hospitals have 10 hospitals reached the value while 27 % failed to reach the target value in the sample hospitals.

Compared with the hospital energy benchmarking of Zhejiang Province, in terms of EUI, only one of the 30 sample hospitals, accounted for 3%, reached the guide value. Three fifths of sample hospitals, accounted for 60%, did not reach the constraint value. However, in terms of EPP, there are only 23% did not reach the constraint value. Advanced value, while 8 hospitals did not reach the Reasonable value. Overall, 30% reached the advanced

In contrast to the hospital energy benchmarking of Jiangsu Province, in terms of EUI, there is no one of the 30 sample hospitals reached the Advanced value. Accounted for 47% of sample hospitals did not reach the constraint value. However, in terms of EPP, there are only 6% did not reach the constraint value.

In conclusion, the evaluation results based on the hospital energy benchmarking of Jiangsu Province Jiangsu and Zhejiang are similar, but have great

differences with the hospital energy benchmarking of Shanghai. Furthermore, there is a big gap between the evaluation results obtained by using EUI and EPP which contribute to completely opposite results.

5.2 Study of Energy Consumption Evaluation using Regression method

According to the correlation analysis, the construction area (x1), the number of outpatient and emergency patients (x2) and the number of beds (x3) of the above three factors were taken as the four influencing factors of the energy consumption (Y). The Stepwise regression model of energy consumption of sample hospitals was employed to find the significant factors.

The results of stepwise regression model in Table 3 showed Y of each sample hospitals is successfully established only with the floor area (x1), which becomes a unitary linear regression model. Number of outpatient (x2) and number of beds (x_3) are considered as the factors less significant than floor area (x_1). It was found that there was no strong collinearity among the three variables while a strong correlation between them.

In the conclusion, firstly, the influence of the number of outpatients and hospital beds on energy consumption is less than the building area; secondly, the number of outpatients and hospital beds cannot improve R^2, which fails to achieve the function of improving prediction accuracy.

According to the energy efficiency ratio calculation method and evaluation method mentioned above, the evaluation method for the sample model in this study can be obtained as follows: when $R < 0.87$, the hospital is high energy efficiency hospital while the hospital is low energy efficiency hospital when the $R > 1.10.$

In this study, regression models were established for different functional types of hospitals respectively, but the conclusions obtained were not significantly different from the above conclusions, so they will not be repeated here.

6. DISCUSSION

6.1 Fineness of category classification impact evaluation results.

From the analysis of energy consumption factors, it is found that different types of hospitals of the same grade are affected by the same type of factors in different trends. According to the service level, technical level, medical conditions, management level, hospitals in China are divided into three class and ten grades.

	Shanghai	Zhejiang	Jiangsu
Top Class	GH SH	Class Ⅲ Class Ⅱ	Class Ⅲ Class Ⅱ Class Ⅰ Other
Secondary Classification	Floor area of unit bed Per outpatient of floor area	——	Floor area Outpatient
Evaluation Index	EUI	EUI EPP ECCUF	EUI EPP
Metric	Reasonable value Advanced value	Constraint value Reference Value Guidance values	Constraint value Reference Value Guidance values
Date of Issue	2012	2019	2021

Table2 List of hospital energy consumption

Regression statistics				
Multiple R	R Square	Adjusted R square	Standard error	P-value
0.99	0.98	0.94	1535.79	1.74E-26

Table3 List of regression statistics and P-value of regression model.

According to the medical treatment and service scope hospitals in China also can be divided into at least seven types. The former is related to the medical technology level of the hospital.

It is worth mentioning that different medical pertinence further leads to different requirements for hospital construction. Therefore, the standard of hospital construction in China is based on the type of hospital rather than the grade of hospital.

When the evaluation index of hospital building energy consumption is divided according to three grades, it ignores the difference of the construction demands of different types of hospitals, while the differences in the level of medical technology are ignored when classifying only types. Even if clustering method be used to classify hospital types, clustering factors still need to be carefully selected.

6.2 Scientific selection of evaluation indicators

Common indicators for evaluating hospital energy consumption include EUI, EPP and EPB, etc. As mentioned above, most foreign studies believe that the per-bed energy consumption is a most reasonable

evaluation method. But it's important to realize that these kinds of conclusions come from countries with highly developed health care industries. Whether this evaluation is applicable to the medical and health care is still at a relatively low level, which still needs to be studied in the rapidly developing Chinese hospitals. At the same time, in the face of the phenomenon that conclusions from different indicators are inconsistent, it is necessary to have a more exact reference method for indicators while benchmarking multiple standards.

6.3 The evaluation method needs the association of activity and inertia.

Although compared with static index evaluation methods such as quota evaluation, regression model can be regarded as a dynamic evaluation method. However, this method relies on a perfect energy consumption database, and the quality and quantity of each building's energy consumption and its influencing factors are directly related to the accuracy of the model obtained. At the present stage, there is no completely database for China hospital building. It can be seen from the results of the regression method that the quota evaluation and regression method are limited in adapting to the needs of China's medical and health care and the situation of rapid construction and development. In addition, in view of the increasing impact of hospital energy consumption on medical and health demand and the decreasing impact of hospital building energy conservation requirements in the future, how to divide the impact of the two also needs to be further studied. Therefore, it is necessary to combine the dynamic and dynamic evaluation method in the evaluation of hospital energy consumption.

7. CONCLUSION

The evaluation of hospital building energy consumption is an important part of building energy efficiency management. Many factors that affect hospital building energy consumption determine the complexity of the analysis and evaluation of hospital building energy consumption. This paper summarizes a number of analysis angles involved in the evaluation of hospital building energy consumption. In the process of selecting different evaluation indexes, the analysis of hospital building energy consumption can play a positive role. At the same time, the evaluation indexes are compared according to the available effective information and application scenarios to determine the reasonable choice of indexes.

In this study, based on the energy consumption data of 30 sample hospitals in Shanghai and the information of buildings and service volume, the problems existing in the establishment and use of hospital energy consumption quota in China at the present stage are studied and analyzed. Under the condition of rapid construction and development of hospital construction and health and medical level in China.

The evaluation of hospital building energy consumption generally relies on static indicators and the indicators are not clear and need to be solved from a more basic perspective.

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