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Sensitivity Analysis on the Operating Energy Efficiency of Public Buildings in China

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ABSTRACT

With the development of sustainable concepts and zero-energy buildings, improving the energy efficiency of the overall operation phase of the building has an increasing impact on reducing energy consumption. Currently, most studies lack the analysis of key influencing factors of building energy efficiency evaluation, and thus cannot provide specific suggestions for the building energy efficiency. This paper aims to comprehensively evaluate the energy efficiency of the operation stage, which accounts for the largest proportion of the whole building life cycle, and conduct a sensitivity analysis on various subsystems and equipment of building energy systems to find the key factors and hurdles that affect the improvement of the energy efficiency. This work will provide specific suggestions for the energy performance diagnosis and renovation of existing buildings in China, and is of great significance to comprehensively evaluating high-consumption building equipment and improving the overall building quality.

Keywords: public buildings, operation stage, energy efficiency evaluation, sensitivity analysis, energy efficiency improvement

NONMENCLATURE

Abbreviations	
EEIR	Energy Efficiency Impact Rate
E	Excellent
G	Good
A	Average
P	Poor
V	Very Poor
Symbols	
i	Energy efficiency grade
S_i	Public building operation energy efficiency score value
S_o	Operating energy efficiency score value of public buildings under the benchmark state

1. INTRODUCTION

Accompanied by the fast progress of urbanization, investigating building energy consumption and researching energy efficiency strategies play an important role in sustainable urban development. It will also be of great significance to achieving carbon peaking and carbon neutrality as soon as possible [1]. As an important issue in sustainable development, energy efficiency is particularly difficult to assess for some consumers[2]. For such assessment, the energy efficiency label is potential solution widely praised for its simple and intuitive structure, easy-to-understand, small investment, and obvious benefits. Studies have shown that public buildings consume a great amount of energy during the entire life cycle, so their energy efficiency has received extensive attention from many researchers[3–6].

At present, many countries have proposed various evaluation standards related to the building energy efficiency[7–9]. Although China's green building evaluation research started late, an increasingly rich evaluation system has been formed following the design principle of energy conservation and emission reduction. However, a survey has found that the actual energy-saving effect of green buildings is still far from expectations [10]. The reason is that high energy consumption caused by users in the operation and maintenance phase has not been accurately predicted and properly managed [11].

To fill this research gap, a public building operation energy efficiency evaluation index system has been established in the previous research[12], which can evaluate the overall energy conservation status of public buildings in the whole operation stage. Based on the evaluation index system, this study conducts an in-depth analysis of various energy-consuming systems that affect building energy consumption and evaluates the impact of system parameters on the model output through a sensitivity analysis, to discover key factors affecting energy efficiency levels, thereby effectively improving the high energy consumption of buildings, and finally provide guidance for energy-efficiency diagnosis and renovation of existing buildings in China. This research is of great significance to improve the energy efficiency in renovation projects of existing public buildings in China and over the world.

2. RESEARCH METHODOLOGY

During the operation phase of the building, seven energy-consuming systems are involved, including the HVAC (Heating, Ventilation and Air-Conditioning), electrical lighting, water supply and drainage, and power supply and distribution system. These energy-use systems jointly determine the energy efficiency level of the building.

In order to understand the influence of a single variable change on the overall energy efficiency level of the building[13], the local sensitivity analysis is used to quantify the influence of different parameters on the comprehensive score and evaluation level of energy efficiency as the model output, which is the evaluation results through the evaluation model of the operational energy efficiency for public buildings and the results are divided into five grades[12]. First, the benchmark building is defined to have all index items of the building's energy-use system at the "average" level, where the value of each index item is defined as the "reference value", to facilitate subsequent calculations and comparative analyses. At the same time, according to the relevant standards and regulations on energy conservation of public buildings in China, the interpolation method is used to select the value range of each index and the corresponding value of energy efficiency grades 1-5. An accurate evaluation needs to consider not only the equipment parameters, but also the real performance during actual operation. Table 1 lists the value ranges and benchmark values of index items used for the sensitivity analysis of public buildings.

Based on the established evaluation index system, a software for energy efficiency evaluation of public building operation was developed, and static energy efficiency simulation was carried out by individually changing the parameters of each index item within the value range. Figure 1 shows the process framework of software operation. The results of the sensitivity analysis are also mainly based on the evaluation result variation from the developed software.

Finally, in order to obtain the quantitative relationship between the indicators and the energy efficiency improvement, this paper defines the "Energy Efficiency Improvement Rate (EEIR)". This means that in the baseline state, with the improvement of the energy

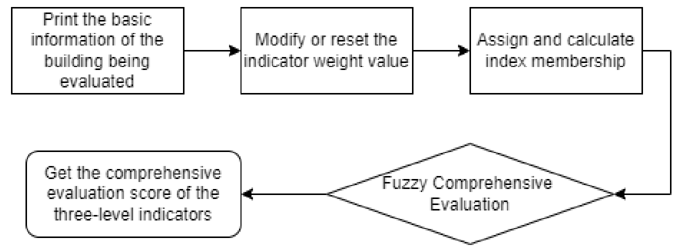

Fig. 1 Software Evaluation Process

efficiency level of a certain indicator, the ratio of the impact of the overall operation energy efficiency of public buildings. In other words, the ratio of the impacted score to the baseline state. The formula is as follows:

$$\Delta \mathrm{E} = \frac{S_i - S_o}{S_o} \times 100\% \qquad \text{Eq. (1)}$$

Where EEIR is the energy efficiency impact rate; S_i is the operating energy efficiency score value when all other indicators take the benchmark value and one indicator takes i, i=1,2, 3, 4, 5; S_o is the operating energy efficiency score value of public buildings under the benchmark state.

3. RESULTS

The software simulation results shows that there are 12 indicators which have a significant impact on the energy efficiency evaluation level of public building operations. And the final evaluation grades of these 12 indicators changed significantly, from "poor" to "average", while the others indicators remained at the "average" level without obvious changes.

The relationship between the energy efficiency rating of these 12 important indicators and the final evaluation score is shown in Figure 2. Upgrading the energy efficiency level from level 5 to level 1, the operating energy efficiency score of public buildings has been significantly improved. And combined with the results of the previous simulation, the final energy efficiency level is also improved from “poor” to “average”, especially for the changes in the energy efficiency of cold and heat source units, energy consumption of elevator and winter indoor temperature. Figure 3 shows the results of the EEIR for all indicators. The energy efficiency improvement rate of each indicator from level 5 to level 1, the cold and heat source

Table 1 Indicator Items for Sensitivity Analysis of Public Buildings

Index number	Variable	Ranges	Reference value	Unit
1	Cooling/Heating Energy Efficiency of Cold/Heat Source Units	2.9/3.1/3.3/3.5/3.7	3.3	—
2	Operation energy efficiency ratio of Cooling water	16.3/17.7/19.1/20.5/21.9	19.1	—
3	Transfer coefficients of chilled water	27/29/31/33/35	31	—
4	Operation energy efficiency ratio of Cooling terminal device	7.95/8.65/9.35/10.05/10.75	9.35	—
5	Summer indoor temperature	24.6/26.6/28.6/30.6/32.6	29	℃
6	Summer indoor humidity	55/65/75/85/95	75	%
7	Energy saving control of cooling system	E/G/A/P/V	A	—
8	Fan efficiency	E/G/A/P/V	A	—
9	Indoor carbon dioxide concentration	513/653/793/933/1073	770	ppm
10	Energy saving control of ventilation system	E/G/A/P/V	A	—
11	Lighting equipment effects	E/G/A/P/V	A	—
12	Lighting power density	E/G/A/P/V	A	—
13	Indoor illumination	E/G/A/P/V	A	—
14	Energy saving control of lighting system	E/G/A/P/V	A	—
15	Operation energy efficiency ratio of Cooling tower	115.6/125.8/136/146.8/157.6	133.6	—
16	Operation energy efficiency ratio of Domestic hot water system	0.3/1/1.7/2.4/3.1	1.742	—
17	Hot water transmission coefficient	27/29/31/33/35	31	—
18	Operation energy efficiency ratio of Terminal system in heating periods	7.95/8.65/9.35/10.05/10.75	9.35	—
19	Winter indoor temperature	9.5/12.5/15.5/18.5/21.5	15.8	℃
20	Winter indoor humidity	5/15/25/35/45	25	%
21	Energy saving control of heating system	E/G/A/P/V	A	—
22	Energy consumption of elevator	6195/19363/32531/45699/58867	30600	kWh
23	Energy saving control of elevator system	E/G/A/P/V	A	—
24	Pump efficiency of the water supply system	E/G/A/P/V	A	—
25	Operation energy efficiency ratio of hot water	16.3/17.7/19.1/20.5/21.9	19.1	—
26	Energy saving control of water supply system	E/G/A/P/V	A	—
27	Transformer energy efficiency	E/G/A/P/V	A	—
28	Renewable energy generation rate	0.005/0.015/0.025/0.035/0.045	0.025	—
29	Energy saving control of electricity supply and distribution system	E/G/A/P/V	A	—

unit is the largest, which is 4.07%, followed by the energy consumption of elevator, 3.19%, and the energy-saving control of the elevator system, cooling system and heating system is 3.19%, 2.60% and 2.25%, respectively. However, the ΔE of the indoor humidity in summer is the smallest, which is only 0.49%.

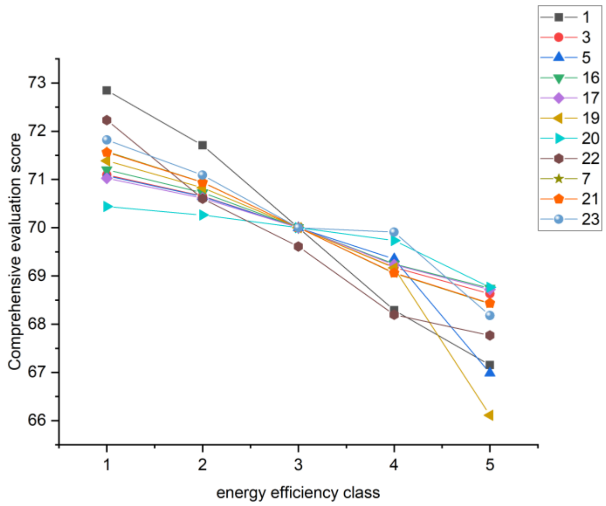

Fig. 2 Energy Efficiency Rating and Overall Evaluation Score

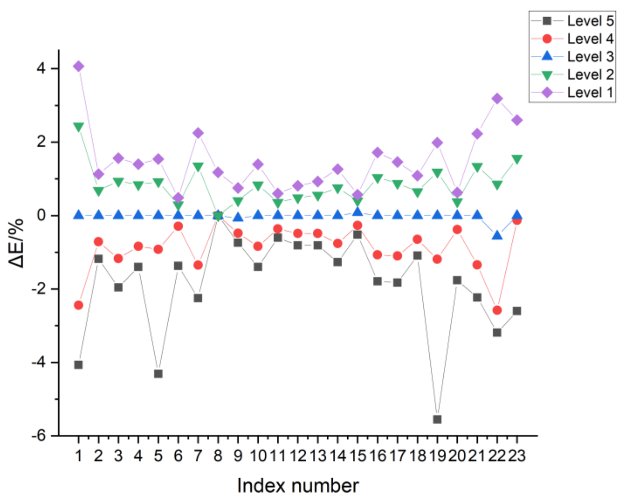

Fig. 3 Level 1 - Level 5 Energy Efficiency Impact Rate

4. CONCLUSION

This study conducted a local sensitivity analysis of 30 indicators that affect the energy efficiency of public buildings during the operation phase and identified 12 important indices that have a significant impact on the overall energy efficiency evaluation results of the building. in the process of upgrading the energy efficiency level of all indicators from level 5 to level 1, the overall energy efficiency of public buildings has been improved. When improvement is conducted from level 5 to level 3, the overall energy efficiency exhibited the greatest improvement. However, for the whole building, the energy efficiency level of each equipment should be guaranteed to be at least level 3 or above in the actually design and renovation to comply with energy efficiency standards. Besides, the EEIR of some indicators upgraded from level 3 to level 1 exceeded others that were upgraded to level 1. In actual building renovation, priority can be given to improving the energy efficiency level of high-energy-consumption equipment by comprehensively considering economic and energy-saving benefits for reaching more cost-effective solutions. By applying the results of the building energy evaluation system, the efficiency level of each energy system can be examined and then take the most effective improvement measures. At the same time, it can also strengthen the management of building energy consumption and advocate more standardized building energy conservation behaviors.

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