Comprehensive Evaluation Method of Office Building Energy Consumption Based on Improved Multi-index

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Abstract. In view of the imperfection in the selection of energy consumption characteristics and energy conservation evaluation methods, this paper proposes an energy consumption analysis and energy conservation evaluation method suitable for office buildings. Through the analysis of office building energy consumption monitoring layer data, establishing standard of building energy consumption data sets, including office building day by day, month by month, year after year way of energy consumption and heating and cooling is analyzed, and aiming at the problem of building energy efficiency evaluation index weights are difficult to determine, combined with the feature of energy consumption was proposed to build multiple indexes comprehensive evaluation of energy consumption. Through the example of office building, the evaluation results are verified, which proves that this method can evaluate the energy consumption of buildings reasonably and feasible, and provides a new idea for the comprehensive evaluation of building energy conservation.

Keywords: Office Buildings, Building Energy Consumption, Standard Dataset, Energy Saving Index.

1. Introduction

As a typical and main service building, office building has a large flow of people, obvious regional differences in scale, strong seasonal and regional characteristics, and its energy consumption characteristics also show certain rules, attracting the attention of the majority of researchers [1]. Bourassa [2] et al. studied the main influencing factors through the monitoring data of building energy consumption, showing that building height is far more important than size, shape and climate. Yu et al. used E-quest to study the influence of various parameters on the energy consumption buildings [3]. SALEH, SAFA and other scholars conducted statistical analysis on the operation records of construction equipment, found that at present, office buildings have low energy efficiency, unreasonable energy utilization, serious energy waste and great energy saving potential [4-5].

However, the factors influencing energy consumption of office buildings are very complex [6-7]. Current office building energy consumption analysis of affecting factors are mainly qualitative analysis and the energy-saving evaluation theory system is not mature enough [8-9]. Therefore, this paper mainly takes office buildings as the research object, extracts and analyzes the characteristics of building energy consumption, establishes a comprehensive evaluation method for office buildings, and constructs a multi-index comprehensive evaluation model.
2. Theoretical Basis of Model

2.1. Principles and Procedures
Energy consumption of office buildings can be divided into HVAC system, lighting system, power system and others. The whole platform architecture including equipment layer, sensing layer, control layer, monitoring layer and integrated management layer [10]. A large number of monitoring instruments for sub-area monitoring are mixed, and it is not convenient for data storage and mining of building energy consumption. In this paper, the redundant energy consumption data are firstly reduced in dimension to build the standard energy consumption data set, and the key energy consumption indicators are selected based on the building data, to identify the energy conservation of building energy consumption through the data collected in real time. This can not only avoid too detailed statistics of energy consumption data and itemized measurement data, but also reduce the installation of itemized measurement system of energy consumption, which greatly saves the cost of energy consumption supervision and evaluation.

2.2. The Data Source of Improved Multi-index Comprehensive Evaluation Model
The energy terminals of ordinary office buildings can be divided into three parts: lighting power, heating and ventilation equipment and other equipment. Combined with the individual characteristics of the building, the fluctuation of the use of lighting equipment with time is not large. As the main equipment to maintain room temperature, the energy consumption of HVAC is greatly affected by climate factors. The three components of energy consumption in existing buildings are the main reasons for the difference in total energy consumption. Commonly used evaluation indexes of buildings are certain factors, such as building area, equipment use and number of people, to indicate the mean level of a unit [11]. However, for different buildings, different regions and even different countries, the research and consideration of building energy consumption factors are different, resulting in different evaluation effects of these indicators on office buildings. Therefore, multiple indicators need to be improved to comprehensively evaluate the energy consumption of buildings.

3. Analysis of Energy Consumption Characteristics of Office Buildings

3.1. Introduction of Selected Office Buildings
The office building studied in this paper is located in Xi'an, Shaanxi province, which has a warm temperate sub-humid continental monsoon climate with four distinct seasons, moderate rainfall and mild climate. Five representative buildings were selected for further analysis. As shown in table 1, details of building functions and heating and cooling methods are given. Office building K and office building L were constructed in the 20th century, office building D was constructed in 2003, and office building C and office building J were constructed recently, and air conditioning units were used for cooling, which is better than office building D and office building K and L. In terms of heating, building A adopts municipal steam heating, while building A and C use gas-fired boilers for heating. Among them, office building C was completed in 2015, and was rated as a one-star green building. At the same time, the sub-point position monitoring of the five office buildings is normal, which can effectively monitor the energy consumption information in the buildings.
Table 1. Heating and cooling mode of five office buildings

| Office buildings | A   | C   | D   | J   | L   |
|------------------|-----|-----|-----|-----|-----|
| Construction year| 2006| 2015| 1999| 2016| 1980|
| Construction area| 42058| 44532| 26000| 33529| 6540|
| Air conditioning area| 30814| 20000| 22000| 33529| 6540|
| Heating area| 11244| 20000| 22000| 33529| 6540|
| Air conditioning form| Fan coil + fresh air| Others| VAV| VRV| VRV|
| Heating form| Others| Others| Municipal| Radiant heating| Radiator heating|
| Construction layer| 7| 27| 14| 31| 7|

3.2. Analysis of Energy Consumption Characteristics

The main building energy consumption can be described as: steam supply to the dining room to cook, living hot water through the heat exchange plate as well as the equipment is mainly used for winter heat exchange to district heating. Meanwhile, building D using lithium bromide gas, is used for air conditioning in winter heating or used for summer air conditioning refrigeration. This caused by differences can flow at the end of the office building energy consumption differences.

According to the energy flow diagram, energy use can be represented by the following formula:

\[ E_{total} = E_{lighting} + E_{HVAC} + E_{power} + E_{others} \]  

\[ \text{Gas}_{total} = \text{Gas}_{dining} + \text{Gas}_{HVAC} + \text{Gas}_{domesticwater} + \text{Gas}_{others}. \]  

\[ \text{Steam}_{total} = \text{Steam}_{dining} + \text{Steam}_{heat} + \text{Steam}_{hotwater} + \text{Steam}_{other}. \]

Though analyzing, the power consumption of each building presents an obvious seasonal variation. The main reason for the seasonal fluctuation of energy consumption is the high demand for heating and cooling in winter and summer, while the power consumption is relatively high in summer. In addition, the monthly energy consumption trend of electricity, gas and steam in the five office buildings is relatively stable with little fluctuation. The water consumption before and after July and November is relatively high. According to the energy flow chart, water consumption is mainly used for domestic water, toilets and kitchens, while office workers, as the main water users, are the main factors affecting the water consumption.

The study found that the office buildings showed outstanding response characteristics to the season, and the monthly energy consumption also showed obvious regularity. Based on this, an energy consumption index analysis model is proposed to analyze the energy consumption of five office buildings. Before data analysis, data need to be centralized and integrated processing. For example, for building energy with different dimensions (including electricity, oil and natural gas), it can be converted into the same dimension tce according to the conversion coefficient, so as to directly calculate building energy consumption\(^{12}\).

4. Comprehensive Evaluation Index System of Office Building Energy Consumption

4.1. Establishment of Building Energy Consumption Standard Data Set

The standard energy consumption data set is established as shown in table 2. Among them, the building types are divided into commercial office buildings and government buildings; Building structure is divided into wooden structure and non-wooden structure; Types of building equipment are divided into electric and non-electric equipment according to the use of energy. Electric equipment refers to equipment driven by electric energy, such as refrigerators. Non-electric means equipment powered by fuel oil, natural gas and other energy sources, such as gas water heaters.
Table 2. Building standard energy consumption data set

| Classification of data       | The specific content | The data format       | The data unit | describe          |
|-----------------------------|----------------------|-----------------------|--------------|------------------|
| Building information        | Architectural space type | Unsigned integer  | None         | Room/corridor    |
| Personnel information       | PMV                  | Unsigned integer     | None         | -3~+3            |
| Environmental information   | The air temperature  | Single-precision     | °C           |                  |
|                             | Air relative humidity| Air relative humidity| %           |                  |
| Building energy information | The total power      | Single-precision     | kW·h         |                  |

4.2. Selection of Building Energy Saving Characteristic Indexes

This section aims to establish an evaluation index system of building energy consumption. Energy saving effect of factors including building area, office number, annual output value, and so on, but the different characteristics of building energy consumption, these factors are also different weight, the accurate calculation of the weights of these factors and more difficult, although the AHP and grey correlation, the hierarchical clustering method was used for determine the energy consumption index weights, but these methods are based on detailed data and based on large sample [1].

Due to the monthly data are sparse, it is impossible to use the conventional mathematical means to establish forecasting model. In order to explore the energy consumption of different buildings, four monthly divisions are introduced: Natural month: the seasons in which cooling and heating are not required, referring to April, May and October; Heating month: the season in which heating is required, i.e. December, January, and February; Cooling months: the season in need of cooling, referring to the months of July, August and September; Semi-natural month: refers to the alternating seasons of passive cooling and natural heating, refers to March, June and November.

In addition, this paper introduces the evaluation factors in table 3 below, taking each index in the table as an evaluation dimension, and the value of each index is the coordinate of the multidimensional evaluation space. In a sense, such multidimensional evaluation also assumes that their weights are equal, and the indexes are orthogonal and independent of each other. Secondly, due to the different units and dimensions of different indicators, corresponding normalization should be carried out, and then the energy saving performance of the five buildings should be evaluated based on the above reasons.
Table 3. Evaluation factors of building energy consumption

| Index factor       | Heating month | Cooling month | Natural month | Semi-natural month | Water consumption |
|-------------------|---------------|---------------|---------------|--------------------|-------------------|
| Floor area ratio  | $\bar{E}_1 = \frac{E_1}{S}$ | $\bar{E}_2 = \frac{E_2}{S}$ | $\bar{E}_3 = \frac{E_3}{S}$ | $\bar{E}_4 = \frac{E_4}{S}$ | $\bar{W}_1 = \frac{W}{S}$ |
| The output value ratio | $\bar{E}_5 = \frac{E_1}{P}$ | $\bar{E}_6 = \frac{E_2}{P}$ | $\bar{E}_7 = \frac{E_3}{P}$ | $\bar{E}_8 = \frac{E_4}{P}$ | $\bar{W}_2 = \frac{W}{P}$ |
| Office space ratio | $\bar{E}_9 = \frac{E_1}{B}$ | $\bar{E}_{10} = \frac{E_2}{B}$ | $\bar{E}_{11} = \frac{E_3}{B}$ | $\bar{E}_{12} = \frac{E_4}{B}$ | $\bar{W}_3 = \frac{W}{B}$ |
| Personnel ratio   | $\bar{E}_{13} = \frac{E_1}{O}$ | $\bar{E}_{14} = \frac{E_2}{O}$ | $\bar{E}_{15} = \frac{E_3}{O}$ | $\bar{E}_{16} = \frac{E_4}{O}$ | $\bar{W}_4 = \frac{W}{O}$ |

Although the floor area of different buildings is different, the heating and cooling load is proportional to the heating and cooling area, so it is reasonable to use the heating and cooling area as the index factor. In addition, building area (heating area) and indoor personnel ratio were selected as the main influencing factors for energy consumption of cooling and heating (yellow part in the table). Similarly, since energy consumption is mainly used for lighting, elevators and other living equipment, four indicators should be selected for energy consumption in the natural season (the red part in the table). For daily water use, indoor staff is the most important influencing factor, so the ratio of floor area and office space is selected as the main factor (the green part in the table).

4.3. Analysis of Energy Saving Effect of Office Buildings
According to the comprehensive energy conservation evaluation index established by the above analysis, the energy consumption of five office buildings is compared as shown in figure 1. The smaller the radar area is, the more energy saving the building will be, while the larger the radar area is, the further transformation is needed to reduce the relative energy consumption.

![Figure 1. Qualitative energy saving evaluation model](image-url)
5. Summary
This paper proposed specific analysis on 5 office building and build the standard data sets, including building ontology, building energy consumption equipment, personnel, etc. The research summarized the factors that affect energy consumption and established the improved building energy consumption evaluation multi-index, and found that energy conservation of building D is the least, which need further energy saving analysis and modified. Compared with the software simulation, the improved multi-index comprehensive evaluation model is used to analyze the building energy efficiency, combining qualitative and quantitative factors, which is more in line with the actual condition of the building and can make a more reasonable evaluation for the energy consumption of the building.

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