Analysis of Building Energy Saving Potential in High-speed Service Area Based on DeST Energy Consumption Simulation

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Abstract: High-speed service area buildings are located in specific areas and have special functions, so the research on energy consumption and energy-saving potential of high-speed service area buildings is different from that of conventional public buildings. In this paper, taking a high-speed service area building in Jinan as the research object, The dynamic benchmark model of hourly energy consumption of buildings in high-speed service area is established by using DeST energy consumption simulation software and the reference model is established. Comparing the annual energy consumption of the benchmark model with that of the reference model, this paper analyzes the energy-saving potential of the buildings in the high-speed service area.

1. Introduction
Under the background of dual control of total energy consumption and total carbon emission reduction, the role of building energy conservation has become increasingly prominent. In recent years, scholars at home and abroad have carried out in-depth research on the energy consumption level and energy saving potential of buildings, mainly focusing on residential buildings [1-2], hotel buildings [3], office buildings [4], and other types of buildings.

High-speed service area buildings are located in specific areas and have special functions, so the research on energy consumption and energy-saving potential of high-speed service area buildings is different from that of conventional public buildings. At present, there are few researches on energy consumption and energy saving potential of high-speed service area buildings at home and abroad, which limits the steady progress of building energy saving in high-speed service area to a certain extent. In view of this, this paper takes a high-speed service area building in Jinan as the research object, establishes a dynamic benchmark model of hourly energy consumption of high-speed service area building in the whole year by using DeST energy consumption simulation software.

2. Principles and methods
In this paper, DeST, a building energy consumption simulation software independently developed by Tsinghua University, is used to analyze energy consumption. Based on the concept of "design by stages, simulation by stages", this software realizes the effective connection between buildings and systems, and better solves the problem of coupling between buildings and systems.
DeST dynamic energy consumption model is mainly based on complex heat transfer equations. When calculating the heat transfer equation of building envelope, the envelope is decomposed into several discrete points, keeping the continuity of its temperature in time, and establishing a heat balance formula for each node. See Formula 1 ~ Formula 3 for details, and then get the solution of the heat balance equation, and get the room temperature distribution and load state [5].

\[
\frac{1}{2} c_{pi} \rho_i \Delta x_i \frac{dt}{d\tau} = h_i \left( t_{i,a} - t_i \right) + \lambda_{n+1} \left( t_{i+1} - t_i \right) + \sum_j h_{r,i,j} \left( t_{i,j} - t_i \right) + q_{i,rad} \\
\frac{1}{2} c_{pi} \rho_i \Delta x_i \frac{dt}{d\tau} = \frac{\lambda_{n+1}}{\Delta x_{i-1}} \left( t_{i-1} - t_i \right) + \frac{\lambda_i}{\Delta x_i} \left( t_{i+1} - t_i \right) \\
\frac{1}{2} c_{pi} \rho_i \Delta x_i \frac{dt}{d\tau} = h_{n} \left( t_{n+1,a} - t_{n+1} \right) + \frac{\lambda_n}{\Delta x_n} \left( t_{n} - t_{n+1} \right) + \sum_j h_{r,n+1,j} \left( t_{n+1,j} - t_{n+1} \right) + q_{n+1,rad}
\]

In which: \( C_{pi} \): Specific heat of the ith difference layer; \( \rho_i \): Density of the ith difference layer; \( \Delta x_i \): Thickness of the ith difference layer; \( t_i, t_{i+1} : \) Node temperature; \( \lambda_i \): Thermal conductivity of the ith difference layer; \( t_{1,a}, t_{n+1,a} \): The air temperature immediately adjacent to the 1st and (n+1th) nodes; \( t_{1,j}, t_{n+1,j} \): Environmental surface temperature corresponding to the inner and outer surfaces of the enclosure structure; \( h_{r,i,j}, h_{r,n+1,j} \): Heat transfer coefficient between inner and outer surfaces of envelope and long-wave radiation in surrounding environment; \( q_{1,rad}, q_{n+1,rad} \): The radiant heat obtained by the 1st and (n+1th) nodes.

3. Establishment and calculation of building energy consumption model in high-speed service area

3.1. Overview of building benchmark model

Considering the service characteristics of high-speed service area buildings, a high-speed service area building in Jinan is selected, and the annual hourly energy consumption benchmark model is established. The building has 2 floors above ground, with a total construction area of 3902.79m². The first floor of the building model is 5 meters high, and most of the room functions are restaurants, supermarkets, public toilets, etc. The second floor is 4.5m high, mainly for guest rooms and lounges. See Figure 1 and Figure 2 for the layout of building plane structure.

![Fig. 1 Layout of the first floor plane structure of the model](image1)

![Fig. 2 Layout of the two-story plane structure of the model](image2)

3.2. Building reference model parameter setting

The properties of envelope materials are shown in Table 1.
Table 1 Thermal parameters of enclosure structure

| Name of enclosure structure | Enclosure structure material                                      | Heat transfer coefficient/[W/(m²•K)] |
|-----------------------------|-------------------------------------------------------------------|-------------------------------------|
| External wall               | cement mortar20mm+Heavy mortar clay370mm+lime mortar20mm         | 1.519                               |
| Roofing                     | cement mortar20mm+cellular concrete50mm+ armoured concrete 130mm+cement mortar15mm | 1.943                               |
| Internal wall               | cement mortar20mm+ ceramsite concrete 180mm+cement mortar20mm    | 1.515                               |
| Floor                       | cement mortar25mm+ armoured concrete 200mm+cement mortar20mm+ glass wool 15mm | 1.516                               |
| Exterior window             | ordinary insulating glass (medium altitude 9mm)                  | 3.100                               |

Air conditioned area room type, personnel density, lighting, equipment thermal disturbance and interior design parameters are shown in Table 2.

Table 2 Design parameters and environmental control parameters of functional rooms

| Room type | Summer | Winter | Personnel density | Lighting thermal disturbance | Equipment thermal disturbance | Fresh air volume |
|-----------|--------|--------|-------------------|-------------------------------|-------------------------------|------------------|
|           |        |        |                   |                               |                               |                  |
| Restaurant| 25     | 40~60  | 20                | 35~50                         | 0.50                          | 13               |
| Supermarket| 27    | 50~65  | 20                | 40~55                         | 0.40                          | 12               |
| Office    | 25     | 40~60  | 20                | 35~50                         | 0.10                          | 18               |
| Guest room| 26    | 40~65  | 19                | 35~55                         | 0.07                          | 25               |
| Crush-room| 26   | 40~65  | 20                | 35~50                         | 0.30                          | 11               |

The lighting schedule of indoor personnel and equipment is defined according to the actual operation of the actual high-speed service area. In addition, the cold source of the building is centrifugal refrigeration unit, and the heat source in winter is air source heat pump.

3.3. Building benchmark model energy consumption simulation calculation

The standard model of high-speed service area is simulated by DeST software, and the air conditioning system, lighting and equipment, domestic hot water and other equipment are set respectively. The energy consumption of special functions is not included in the calculation index of building energy consumption.

Figure 3 shows the monthly breakdown energy consumption distribution of the building benchmark model in the high-speed service area.
It can be seen from Figure 3 that the total annual energy consumption of the building in this expressway service area is 592,200 kWh/a, and the energy consumption per unit building area is 151.74kWh/m²·a. Among them, air conditioning energy consumption accounts for 43.93%, lighting energy consumption accounts for 27.98%, and domestic hot water energy consumption accounts for 15.99%. Electricity consumption accounts for about 90% of the total building energy consumption, and the rest is provided by coal. From the simulation results, the energy consumption of air conditioning is high in summer; the energy consumption of water supply and drainage, lighting and equipment remained basically stable throughout the year.

4. Building energy saving potential analysis

Establish a reference model in accordance with the requirements of the "Design Standard for Energy Efficiency of Public Buildings" (DB37/5155-2019). By comparing the annual energy consumption of the benchmark model and the reference model, Analysis of energy saving potential.

4.1. Reference model parameter setting

In the aspect of enclosure structure, the exterior wall adopts 50mm thick polystyrene foam thermal insulation material, the thermal insulation form is external thermal insulation, and the heat transfer coefficient is 0.581W/ (m²·K); The roof adopts 50mm thick polyurethane rigid foam thermal insulation material, the thermal insulation form is inverted external thermal insulation, and the heat transfer coefficient is 0.536W/ (m²·K); The outer window material is hollow (high permeability type) plated with low-e film, and the heat transfer coefficient is 2.4W/ (m²·K).

Efficient LED energy-saving lamps replace the original lamps; The centrifugal chiller with high efficiency frequency conversion is used to replace the original air conditioner with fixed frequency centrifuge; Using air source heat pump instead of coal-fired boiler to produce domestic hot water.

4.2. Calculation of energy consumption by reference model

Input the adjusted model parameters into DeST energy consumption software to obtain the monthly building energy consumption of the reference model, see Figure 4 for details.
Fig. 4 Monthly breakdown energy consumption distribution of high-speed service area buildings

The simulation results show that the energy consumption of air conditioning system accounts for 36.82% of the total building energy consumption in the whole year, and the energy consumption of lighting system accounts for 28.58% of the total building energy consumption in the whole year. The energy consumption of indoor equipment accounts for 14.63% of the total building energy consumption in the whole year, and the energy consumption of water supply and drainage system accounts for 17.50% of the total building energy consumption in the whole year. Other energy consumption accounts for 2.47% of the total building energy consumption in the whole year. Compared with the reference model, the annual energy consumption of the reference model of high-speed service area buildings with energy-saving measures is reduced by 29.28%, and the energy-saving effect is remarkable.

4.3. Analysis of Building Energy Saving Potential

In order to deeply analyze the energy-saving potential of high-speed service area buildings, the energy consumption of the benchmark model and the reference model is compared and analyzed, as shown in Figure 6.

Fig. 5 Comparison of energy consumption changes of each sub-item between benchmark model and reference model

It can be seen from Figure 5 that the annual air conditioning energy consumption of the reference model is reduced by 106,000 kWh/a compared with that of the reference model, and its energy saving accounts for 61.11% of the total building energy saving; Compared with the reference model, the annual lighting energy consumption of the reference model is reduced by 45,900 kWh/a; the annual water supply and drainage energy consumption of the reference model decreased by 21,400 kWh/a.

5. Summary

Energy consumption modeling and energy saving potential analysis of buildings in high-speed service areas are of great significance for checking the problems existing in the process of building energy use.
and improving the energy efficiency level of buildings. The energy-saving potential of high-speed service area buildings is analyzed by comparing the annual energy consumption of the benchmark model and the reference model.

The total annual energy consumption of the building benchmark model in high-speed service area is 592,200 kWh/a, and the energy consumption per unit building area is the main energy consumption object; the annual total energy consumption of the reference model is 418,800 kWh/a, which is 29.28% lower than the reference model of 592,200 kWh/a, and the energy saving effect is good. It shows that the comprehensive performance improvement of HVAC system, enclosure structure, lighting fixture and domestic hot water heat source can effectively reduce the energy consumption of existing high-speed service area buildings.

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