Research on the Design of Building Envelope Based on DeST

Zhenzhong Guan, Lei Qu and Yanxin Xu
School of Architecture and Urban Planning, Shandong Jianzhu University, Jinan, Shandong Province, 250101, China
*Corresponding author’s e-mail: sdjzuql@163.com

Abstract. School buildings in China have unique features and rules of use. The indoor thermal environment during the study period is very important, but it can be ignored during the summer vacation and winter vacation. It is very difficult to determine the parameters of building envelope through the designer’s experience in order to ensure a good indoor thermal environment and energy consumption level of school buildings. The design of building envelope can be optimized by DeST. In this paper, the design scheme of an experimental building in a school in Beijing is simulated by DeST. Not only were the defects of the first scheme analyzed, but the optimization measures were also proposed. Finally, the goal of low energy consumption and high comfort was achieved.

1. Introduction

With the progress of science and technology and the improvement of energy-saving consciousness, the quality of indoor thermal environment and the total energy consumption of buildings are more and more concerned[1]. School buildings in China have unique features and rules of use, such as HVAC systems that do not operate daily during heating or cooling periods because of winter and summer vacations. The HVAC system only works five days a week because of the weekends. Classrooms are provided for students to attend classes during the day, so there is no need to maintain a comfortable ambient temperature at night. That means the HVAC system can be kept running at low power or even stopped at night. As building plans become more and more complex, energy-saving requirements and room comfort can no longer be achieved by experience alone. DeST can be used to predict the base room temperature of a building under natural conditions and to calculate the load of HVAC system meeting the room temperature. Feng[2] studied the influence of the insulation thickness, heat transfer coefficient of windows and window ratio to wall on building energy consumption in cold area, and determined key parameters of energy-saving design of near-zero energy buildings. Peng[3] studied the annual hourly energy consumption and air-conditioning load of an office building in Nanjing, and tested the effectiveness of energy-saving measures with DeST.

In this paper, the design of an experimental building in a school in Beijing is studied by DeST. Through the simulation, analysis and optimization of the scheme, the goal of low energy consumption and high comfort was achieved.

2. The first scheme and analysis of the first simulation results

2.1. The first scheme
The project is a five-story experimental building at a school in Beijing. The floor plan of the 5th floor is shown in Figure 1. The size of the building is 65.4m × 18.2m and the total HVAC system area is 5421m². DeST simulates the thermal performance of the building and focuses on the thermal properties of the building envelope itself, so the location of doors and windows is not important[4]. The number of ventilation times per room in the building was set at 0.2 ventilation times per hour. Details drawing of joint structure and thermal characteristic parameters of the first scheme are given in Table 1.

Figure 1. Plan of the fifth floor.

Table 1. Details drawing of the structure and thermal characteristic parameters of the two schemes.

| Projects          | Details drawing of joint structure | Thermal characteristic parameter |
|-------------------|-----------------------------------|---------------------------------|
|                   | The first scheme                  | The optimized scheme             |
|                   | Parameter                         | The first scheme                | The optimized scheme |
| **External wall** | Rₐ                                  | 1.219                           | 4.410               |
|                   | K₉                                  | 0.726                           | 0.219               |
|                   | D₉                                  | 2.990                           | 5.182               |
| **Internal wall** | Rₐ                                  | 0.106                           | 1.383               |
|                   | K₉                                  | 2.977                           | 0.620               |
|                   | D₉                                  | 1.486                           | 2.363               |
| **Roof**          | Rₐ                                  | 1.219                           | 4.461               |
|                   | K₉                                  | 0.726                           | 0.217               |
|                   | D₉                                  | 2.990                           | 5.634               |
| **Ground**        | Rₐ                                  | 0.047                           | 4.317               |
|                   | D₉                                  | 0.589                           | 3.776               |
The function of the room is set as "classroom" and the rest time of the HVAC system is set as "determined by the function of the room". Under this operation, many parameters are automatically determined by the software: the winter vacation is from January 15 to February 18, and the summer...
vacation is from July 7 to September 9. The heating period is set from January 1 to solstice January 14, February 19 to March 15 and November 15 to December 31. The cooling period is set from June 1 to July 6. Every weekend the air conditioning system is shut down. The operating hours of the HVAC system are set from 5am to 23pm every day. Although students do not usually start classes at 5am, but rooms need to be heated or cooled in advance to ensure that the temperature is right when the room is used. Other details are given in Table2.

Table 2. Details of the operating time of the HVAC system are shown in the table. Divide the year into weeks, and the result is 52 weeks + 1 day. The HVAC system will not operate on each weekend during the study period.

| Week       | Period              | Operating condition | Limit of room temperature/℃ | Maximum | Minimum |
|------------|---------------------|---------------------|------------------------------|---------|---------|
| No.1~No.2 | Study period        | √                   | 22                           |         |         |
| No.3~No.7 | Winter vacation     | ×                   | No.8~No.12                   | 22      | No.8~No.17 |
| No.8~No.27| Study period        | √                   | No.13~No.15                 | Transition temperature 26 | No.18~No.20 |
| No.16~No.27|                   |                     | No.21~No.27                 | Transition temperature 24 |         |
| No.28~No.36| Summer holiday      | ×                   | No.37~No.43                 | 26      | No.37~No.39 |
| No.44~No.46|                   |                     | No.40~No.42                 | Transition temperature 22 |         |
| No.47~No.52|                   |                     | No.43~No.52                 | 20      |         |

Each person's calorific value and moisture production were set to 61.0w and 0.109kg/Hr, respectively. Other conditions were set as the default value of the software. After running the simulation command to the model, the data of building load and room temperature are obtained (Table 3, Figure 2, Figure 3).

2.2. Analysis of the simulation data of the first scheme
The maximum hourly heat load of the building's HVAC system appeared at 6:00 on February 19, which was 2290.95 kW. Meanwhile, the maximum heat load of HVAC system per unit area was 422.61 kW. This is the first day of school after the winter vacation. Because the classroom is not heated for a long time during the winter vacation, a lot of heat is needed to raise the temperature of the room[5]. The maximum cooling load of HVAC system was 2641.72 kW at 16:00 on July 6, and the maximum cooling load of HVAC system was 487.31 kW. This is the last day of the study period before the summer vacation. It is already summer in Beijing. The solar radiation and human body heat are accumulated in the building during the daytime, so a lot of cold energy is needed to reduce the indoor temperature. That causes a high cooling load on the HVAC system.

Select the second room on the east side (the first room on the east side is the bathroom, so it is not considered) as a typical representative room for the winter natural room temperature comparison. It is considered to be the worst room for indoor thermal environment in winter, and it was named R5-18201. The maximum hourly heating load of the building's HVAC system occurred on February 19, but that day was not chosen for natural room temperature comparisons. Because before February 19th is the winter vacation. Both the first scheme and the optimized scheme are not heated during the period. Such a long cold vacation is enough to cool the building[6]. So February 19 can’t be chosen. The period from 1 January to 5 January (Monday to Friday of the first week) is a very appropriate. The natural indoor temperature of R5-18201 during this period is plotted as shown in Figure 4.
Table 3. Load data of the two schemes during the study period

| Projects | Unit | Before optimization | After optimization |
|----------|------|---------------------|--------------------|
| Total HVAC system area | m² | 5421.00 | 5421.00 |
| Simulated value | | | |
| Maximum m Heating load | kW | 2290.95 | 2136.16 |
| Maximum m Cooling load | kW | 2641.72 | 2585.11 |
| Total Heating load | kW/h | 1275075.60 | 1117239.36 |
| Total Cooling load | kW/h | 254763.35 | 232379.53 |
| Design index per unit area | | | |
| Maximum m Heating load | W/m² | 422.61 | 394.05 |
| Maximum m Cooling load | W/m² | 487.31 | 476.87 |
| Total Heating load | kW/h/m² | 235.21 | 206.09 |
| Total Cooling load | kW/h/m² | 47.00 | 42.87 |
| Design index per unit area in different periods | | | |
| Heating load index of heating period | W/m² | 54.48 | 47.14 |
| Cooling load index of cooling period | W/m² | 18.01 | 16.57 |

Figure 2. The annual hourly load of the HVAC system of the first scheme

Figure 3. The annual hourly load of the HVAC system per unit area of the first scheme

According to the calculation with the data in Figure 4, the natural indoor temperature of R5-18201 is 6.22°C from January 1 to January 5. In most cases, the indoor temperature is about 7~10°C higher than the outdoor temperature. But the natural indoor temperature fluctuates greatly with the change of outdoor temperature. The lowest temperature is below 3°C. Only 13 were above 10°C, but 39 were below 5°C. In a few cases, the indoor temperature is even found to be lower than the external temperature. This shows that not only the building's own thermal insulation performance is poor, and the heating season indoor thermal comfort is also very bad. This shows that not only the thermal insulation performance but also the indoor thermal comfort in the heating period of the building is poor. The room on the south-west side of the fifth floor receives the most solar radiation in summer, so it was chosen for indoor temperature comparison in summer. It's called R5-18183. Choose July 2~July 6 (Monday to Friday of the 27th week) as the comparison period. It can be seen from Figure 5 that the indoor temperature is maintained in the range of 26°C~34°C during this period. The minimum temperature is about 26°C and the maximum temperature is not more than 34°C. Therefore, the indoor temperature from July 2nd to July 6th is in an acceptable range, although it brings load to the HVAC system.
The main reasons of high energy consumption, high total load and low indoor temperature in winter are that the design of envelope structure is too simple and the components are not appropriate, which leads to poor heat preservation and insulation performance[7]. The area of external wall and roof occupies the main proportion in the total area of the building envelope[8]. However, the thickness of the insulation layer at the wall and roof is not enough, resulting in too little thermal resistance. This allows a large amount of heat to be exchanged between inside and outside through the external walls and roof. The ratio of windows and walls in all directions of the building is too large, and the performance of the selected doors and windows is poor. These two factors make it easy for heat to spread out through doors and windows in winter. Such windows and doors make the building vulnerable to high temperatures outside during the summer months. The lack of insulation between the building and the ground makes the heat transfer between the interior and the ground strong, which results in a large amount of heat loss. The lack of thermal insulation for the exposed floor makes it easy for thermal bridge to form at the handover site, which also provides a way for heat transfer.

3. The optimized scheme and analysis of the second simulation results

3.1. The optimized scheme
Due to the unreasonable design of the envelope of the first scheme, the following optimization measures are proposed for the insulation capability of the envelope: (1) Change the glass curtain wall of the second floor to the fifth floor in the south, east and west directions of the building into the wall with the same material as other external walls, and design four windows on the south wall with a size of 2400mm×2700mm. Two windows are designed on the east and west walls, each with a size of 3000mm×2000mm. Double-layer hollow Low-E glass window is used, and the heat transfer coefficient is 2.4w/(m²·K). The glass curtain wall area of the optimized building is 798.72m² less than before, and the window area is 199.68m² more than before. (2) Add one glass sliding door at each end of the corridor from the second floor to the fifth floor, with the size of 3000mm×3900mm. The door is made of ordinary insulating glass with a heat transfer coefficient of 3.1w/(m²·K). (3) The changes of other parts are shown in Table1.

Under the condition that only the structural level and material type of each component in the building are changed and other parameters remain unchanged, the simulation is conducted again. The annual load data and room temperature data were obtained (Table 3, Figure 6, Figure 7).

3.2. Analysis of the simulation data of the optimized scheme
As we can see from Table3, the optimized values are 2136.16 kW and 394.05W/m², which are obviously lower than 2290.95 kW and 422.61W/m² of the first scheme. The date of the maximum of annual hourly load and annual hourly load per unit area of HVAC system is the same as the first scheme (Figure 6, Figure 7). After optimization, the indexes of heating load of heating period and cooling load of cooling period are 47.14W/m² and 16.574W/m² respectively, which are also smaller
than 54.48 and 18.014 W/m². These load data indicate that the overall energy consumption level of the building declines throughout the year with the addition of insulation and the replacement of doors and windows with better insulation.

The optimized scheme natural indoor temperature of R5-18201 during January 1 to January 5 was plotted in Figure 8. The figure shows that the minimum outdoor temperature is -10 °C, but the optimized R5-18201’s natural indoor temperature is more than 5 °C. During most of the period from January 1 to January 5, the temperature was about 10–15°C higher than the outdoor temperature, of which 38 were above 10°C and only 2 were below 5°C. According to the calculation, the average indoor temperature from January 1 to 5 was 8.87°C, 2.65°C higher than before optimization. From the above data, it can be concluded that indoor thermal environment quality and thermal comfort is improved.

Room R5-18183 indoor temperature curves from July 2 to July 6 are given in Figure 9. It can be seen that the room temperature after optimization is very close to that before optimization, with little difference between the two. The indoor temperature of the optimized room is also in the section of 26°C–34°C. The results we had hoped for did not come to pass. The reasons for this phenomenon have been mentioned above. Although these optimization measures can keep heat indoors in winter, they can also prevent heat from spreading out of the room in summer[9]. So the result what we can see is that the natural summer room temperature in a typical room doesn't drop significantly. But it also didn't end badly. The indoor temperature of the optimized room is in the same good range as before.
Table 4. The number of natural indoor temperatures in each section of R5-18201.

| Name              | ≤5  | 5 ~ 10 | 10 ~ 15 | 15 ~ 30 | >30 |
|-------------------|-----|--------|---------|---------|-----|
| Outdoor temperature | 1776 | 1017   | 1127    | 2275    | 165 |
| Before optimization | 461  | 908    | 1108    | 3357    | 526 |
| After optimization  | 126  | 822    | 1102    | 3774    | 536 |

Figure 10. Distribution of the natural indoor temperature of Room R5-18201 during the study period.

Since the temperature of R5-18183 in the two schemes is very close to each other, it is considered reasonable to analyze the annual temperature of R5-18201. The outdoor temperature and the annual natural indoor temperature of the two schemes are divided into five sections: t≤5℃, 5 < t≤10, 10 < t≤15, 15 < t≤30, t > 30(Table4). The temperature distribution is shown in table 5 and figure 24. The proportion of typical representative rooms in the first scheme whose annual room temperature is less than 5℃ is large, and the number of degree hours is 461, which is more than three times as much as the optimized scheme(Figure10). This will greatly increase the building's heat requirement in winter. 15℃~30℃ is a relatively comfortable temperature range for human body, but the number of typical room temperature in the section of 16℃ ~ 29℃ is 3357 in the first scheme, which is much less than the number of 3774 in the optimized one. This proves that the indoor comfort of the latter is better than that of the former. Other sections are not so different. It can be concluded that the optimized scheme is beneficial to reduce the heating load in winter. At the same time, this will reduce the annual building energy consumption.

4. Conclusion
Taking a laboratory building in Beijing as an example, the simulation test was carried out and the data of building load and natural room temperature were obtained.

Through the analysis of the typical room, it is found that the maximum of heat load of the first scheme appears on February 19, and the maximum of the cold load appears on July 6. But because of the simple structure and low performance of heat preservation and insulation, the heat load of the building is larger and the indoor temperature is lower in winter. Such an indoor environment is not conducive to studying in the classroom. However, the indoor temperature of summer is in the acceptable range.

In the optimized scheme, measures such as reducing the area of glass curtain wall, increasing the thickness of insulation layer, and replacing windows and doors with better performance are adopted, so as to improve the thermal insulation performance of the building, and the number of the room temperature in the comfortable section of typical rooms is improved. The total load and energy consumption of the building were also reduced.

It should be noted that the thermal resistance and air-tightness increase with the changes of structure and type of components, but the indoor heat becomes harder to spread from the inside to the outside in summer. As a result, the natural indoor temperature in summer has not been significantly
reduced in the optimized scheme. Therefore, it is worth considering how to ensure the indoor temperature is comfortable in summer when taking optimization measures.

Acknowledgments
This study was supported by Key Laboratory of Renewable Energy Technologies in Building of Shandong Province and Shandong Province Co-innovation Center of Green Building.

References
[1] Xu JF, Ding XZ, et al. (2007) Research of the Thermal Performance Assessment of Building Structure During the Interim Heating. J. Building Energy Efficiency, 35:17-21.
[2] Feng GH, et al. (2017) Research on Energy Efficiency Design Key Parameters of Envelope for Nearly Zero Energy Buildings in Cold Area. J. Procedia Engineering, 205:686-693.
[3] Peng CH, Wang L, et al. (2014) DeST-based dynamic simulation and energy efficiency retrofit analysis of commercial buildings in the hot summer/cold winter zone of China: A case in Nanjing. J. Energy and Buildings, 78:123-131.
[4] Li YY. (2010) The art of writing a scientific article. J. Chinese & Foreign Entrepreneurs, 31:68-73.
[5] Zou Y, Liu TT, et al. (2014) The discussion of energy saving of school buildings by using time-division heating techniques. J. Refrigerator and air-conditioning, 14:87-89.
[6] Wang HW. (2017) Analysis of energy conservation of teaching buildings in primary and secondary school. J. Construction Science and Technology, 15:80-81.
[7] Ning ZC, Zhang Y. et al. (2019) Optimization of Building Envelope of Primary and Middle School Classroom Based on Natural Room Temperature. J. Building Energy Efficiency, 47:89-93.
[8] Wang QK, Wan C, et al. (2011) Analysis on the Influence of Building Envelope to Public Buildings' Energy Consumption. J. Journal of Wuhan University of technology, 33:112-115.
[9] Wang MW, Qin K. et al. (2016) The Influence of Building Envelope Tightness on Office Building Energy. J. Refrigeration and Air Conditioning, 30:345-349.