

Indoor thermal environment of kindergarten building: A case study in China

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Abstract. Based on the building of a kindergarten in Weinan, Shaanxi Province, this paper explores the influence of different envelope structures and heating modes on the indoor thermal environment for the energy saving and thermal comfort of the existing buildings. Using operating temperature as the evaluation index of thermal comfort, the 15 designed schemes were simulated through Energyplus software and actual measurement to obtain the operating temperature change law and annual heating energy consumption value. The envelope structure optimized by choosing energy-saving building materials such as expansion perlite and foam cement is obviously conducive to the improvement of indoor thermal comfort, and the thickness of the insulation layer increases, and the operating temperature increases accordingly; Although the standard effective temperature in intermittent heating mode is slightly lower than that in continuous heating mode, the standard effective temperature rises significantly with the extension of preheating time, which can meet the requirements of thermal comfort. After energy saving transformation, the total heating energy consumption of the kindergarten building is reduced by up to 3644 GJ, and the energy-saving rate reaches 67%.

Keywords: thermal comfort, energy saving, standard effective temperature, envelope structure, intermittent heating

1 Introduction

With the improvement of people's requirements for the quality of life, the indoor thermal comfort problem is increasingly concerned. In our country under the background of "double carbon goal", the transformation of building energy conservation is developing rapidly. It is particularly significant to ensure that the building after energy-saving transformation can still meet the indoor thermal comfort.

Abad Al Waheed Hawila et al. [1] proposed a method to integrate thermal comfort into energy-saving building design and conducted sensitivity analysis through the meta-modeling approach. The results indicated that implementing the suggested strategy could save about 20% of heating energy enhancing occupant thermal comfort. Du et al. [2] pointed out that the thermal performance of wall and roof envelope has a great influence on building energy consumption, through the simulation analysis of a rural residential house in Longzhong area, it is concluded that the heat consumption index of the building can be reduced to 29.13% by reducing the heat transfer coefficient of the envelope structure. Jia et al. [3] analyzed the influence of intermittent heating mode on indoor temperature and building energy consumption from various aspects. The results show that both the intermittent time and the starting time of heating affect the indoor temperature and

energy consumption, and the intermittent time has a greater influence. With the increase of water supply temperature and flow rate, room temperature fluctuation decreases, indoor comfort increases, but heating energy consumption increases slightly. Increasing the thickness of insulation layer plays an important role in controlling the decrease of indoor temperature and reducing heating energy consumption. Li et al. [4] adopted integrated energy-saving transformation measures to transform existing buildings. Compared with the original houses, the transformed houses could achieve energy saving efficiency of 62.6 percent, and the temperature of all indoor rooms increased by about 3 °C. Indoor human thermal comfort has been greatly improved, and the rate of dissatisfaction with thermal sensation has dropped significantly.

The detailed discussion of building heating energy consumption, energy saving transformation measures and indoor thermal comfort changes before and after the adoption of energy saving transformation measures. It is of great significance to reduce building heating energy consumption and improve indoor thermal comfort [4]. Based on the building of a kindergarten in Weinan, Shaanxi Province, this paper compares respectively the impacts of transformation of envelope structure and optimization of heating mode on heating energy consumption and indoor thermal environment, and the operating temperature [5] was taken as the evaluation index of thermal comfort to conduct a comparative

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analysis on the combination of different modes and envelope structures.

2 Model

2.1 Basic information of building

The main part of the kindergarten consists of two "L" shaped buildings, with two connecting corridors in the middle, synthesizing the "quadrangle" shape. However, in order to reduce the time of model establishment and computer simulation, the selected kindergarten building will be simplified during modeling and the corridor part that does not affect the building energy consumption will be deleted. The total construction area of the kindergarten is 9847 m², and the heating area is 8080 m². The main building has three floors, two floors in part, with several rooftop outdoor platforms. The height from bottom to top is 3.9 m, 3.9 m and 4.2 m respectively.

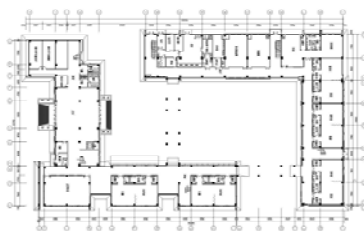


Fig.1. First floor plan of the building

In order to compare the influence of different envelope structures on indoor thermal environment and heating energy consumption, this paper based on the information obtained from the survey, choose the three kinds of envelope structures in Table 1. The 1st kind is the envelope structure that was built earlier in rural areas and did not take thermal insulation measures. The main materials are the type I envelope structure in Table 1. The 2nd kind and the 3rd kind are in last few years the construction form with better building performance of enclosure structure that build, just insulation layer thickness is different.

Table 1. Parameters of different envelope structures

Type of envelope structure	Name of envelope structure	Main material	Heat transfer coefficient/ W · (m ² · K) ⁻¹
Envelope structure I	External wall	240 mm Solid clay brick	2.45
	Roof	120 mm Reinforced concrete	2.11
	External windows	6 mm Common glass	6.14
Envelope structure II	External wall	240 mm Solid clay brick + 40mm expansion perlite	1.03
	Roof	120 mm Reinforced concrete + 20mm foam cement	1.56
	External windows	Double glazing unit	2.30
Envelope structure III	External wall	240 mm Solid clay brick + 80mm expansion perlite	0.61
	Roof	120 mm Reinforced concrete + 40mm foam cement	0.90
	External windows	Double glazing unit	2.30

2.2 Design temperature for heating

According to the Code for Design of Nursery and Kindergarten Buildings, the design temperature of indoor heating for main functional rooms in kindergarten buildings should be 20 °C in winter. Children have higher requirements for thermal comfort, but high requirements are not the same as higher indoor temperature [6].

Children are more active, too high room temperature and too thick clothes are more likely to make children sweat a lot, and then increase the probability of cold and fever. Overall consideration, indoor temperature in kindergarten in winter should be appropriately lowered. The design heating temperature of main rooms such as activity room, dormitory, teacher's office, reception room, health care observation room and morning examination room should be set at 18 °C, lavatory and toilet at 20 °C, and kitchen, hallway and corridor at 16 °C.

2.3 Operating temperature

The operating temperature should be selected as the thermal comfort index when the indoor relative humidity is within the range of human thermal comfort and the airflow speed is low [5]. The operating temperature can comprehensively reflect the comprehensive influence of indoor air temperature and inner wall temperature on human body [7]. In addition, compared with adults, children have poor resistance and cannot accurately express their thermal comfort state, so operating temperature is selected as the evaluation index of thermal comfort.

The calculation formula is as follows:

$$t_{op} = \frac{1}{2} (t_a + t_r) \quad (1)$$

Where, t_{op} -- operating temperature, °C;

t_a -- Indoor air temperature, °C;

t_r -- Average radiation temperature, °C

Indoor air heat balance equation:

EnergyPlus was used for simulation calculation in this paper, which used the reaction coefficient method to calculate the heat transfer of the envelope and the heat balance method to calculate the load. The results were more accurate, and users could set a time step length less than 1 h [8].

According to the conservation of energy, the indoor heat balance equation [9] is as follows:

$$V(cp)_r \frac{t_r(n) - t_r(n-1)}{\Delta\tau} = \sum_{k=1}^N F_i \alpha_i^c [t_r(n) - t_i(n)] -$$

$$q_w(n) + \Phi(n) \quad (2)$$

Where, V -- Room volume, m³; $(cp)_r$ -- Unit specific heat capacity of indoor air, J/(m³ · °C); $t_r(n)$ 、 $t_r(n-1)$ -- Indoor air temperature at moment n and $n-1$, °C; $\Delta\tau$ -- Time interval, s; N -- Total surface area of the envelope structure; F_i -- The area of the i th envelope structure, m²; α_i^c -- Convective heat transfer coefficient of the inner surface of the i th envelope structure, W/m² · °C; $t_i(n)$ -- Internal surface temperature of the i -th envelope structure, °C; $q_w(n)$ -- Heat consumption generated by cold air entering at the moment n , W; $\Phi(n)$ -- The quantity of heat that is carried into the air by the building's heating and air conditioning system, W.

2.4 The selection of schemes

Considering the heating demand of the kindergarten building in the transition season [10], and combined with

the investigation on the opening time of heating equipment in the preliminary survey, the basis of the normal heating period from November 15 to March 15 of the following year, before and after the heating period will be prolonged by one week respectively, That is, November 8 to March 22 of the following year. In addition, the winter vacation of kindergarten is suspended from January 21 to February 12.

The heating mode:

Mode 1:

Using a continuous heating strategy for the building, that is, heating the building 24 hours a day throughout the heating season.

Mode 2-1、2-2、2-3、2-4:

Only from 6:00 to 18:00 on working days from October to April (excluding 3-week holidays), indoor temperature should reach the design value, In the rest of the time, it need only meet the anti-freezing requirements of room temperature not less than 5 °C [11]. If the system starts heating when the room needs heating, the indoor temperature cannot instantly reach the heating temperature required for human thermal comfort, and the longer the intermittent time, the greater the initial heat needed to restore the heating.. Therefore, the heating room needs to be preheated in advance, and the preheating period is usually about 2 hours [12].

In order to be able to meet the indoor temperature requirements at 8 o'clock, the four intermittent heating modes take the preheating time of 2.5 h, 2 h, 1.5 h and 1 h respectively, and turn on the heating system at 5:30, 6:00, 6:30 and 7:00 in the morning respectively. The heating design temperature of different rooms in the building is selected according to Fig.2.

Table 2. Design of simulation scheme

Type of envelope structure	Heating mode	Periods of time of meeting the heating design temperature		Scheme number
		Date	Time	
envelope structure I	1	11.08-01.20 and 02.13-03.22	0:00-24:00	I-1
	2-1		5:30-24:00	I-2-1
	2-2	10.15-01.20 and 02.13-04.15 (Mon to Fri)	6:00-18:00	I-2-2
	2-3		6:30-18:00	I-2-3
	2-4		7:00-18:00	I-2-4
envelope structure II	1	11.08-01.20 and 02.13-03.22	0:00-24:00	II-1
	2-1		5:30-24:00	II-2-1
	2-2	10.15-01.20 and 02.13-04.15 (Mon to Fri)	6:00-18:00	II-2-2
	2-3		6:30-18:00	II-2-3
	2-4		7:00-18:00	II-2-4
envelope structure III	1	11.08-01.20 and 02.13-03.22	0:00-24:00	III-1
	2-1		5:30-24:00	III-2-1
	2-2	10.15-01.20 and 02.13-04.15 (Mon to Fri)	6:00-18:00	III-2-2
	2-3		6:30-18:00	III-2-3
	2-4		7:00-18:00	III-2-4

2.5 The validation of model

The simulation data of the building model in this paper are compared with the measured data [13] to verify the accuracy of the model. Xu et al. [13] measured the indoor and outdoor temperature of a primary school classroom in Guanzhong area for a day. The envelope structure used in the school is the same as that of ordinary buildings selected in this paper. Results As shown in Fig.2, the variation range between simulated outdoor temperature selected from simulated meteorological parameters and measured outdoor temperature on a single day is only 0.16 °C different, but the occurrence time of extreme value is slightly delayed. The simulated indoor temperature changes also lag slightly behind the

measured ones, but the basic trend and fluctuation range are close. The extreme values of measured indoor temperature are 0.67 °C and 8.91 °C respectively, while the extreme values of simulated indoor temperature are 1.15 °C and 8.75 °C respectively, and the difference between the lowest temperature and the highest temperature is 0.73 °C and 0.16 °C respectively, but accounted for only 6.3% and 2.1% of the temperature fluctuations measured. Therefore, it can be considered that the model established in this study can reflect the process of actual building heat transfer.

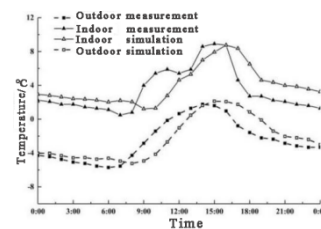
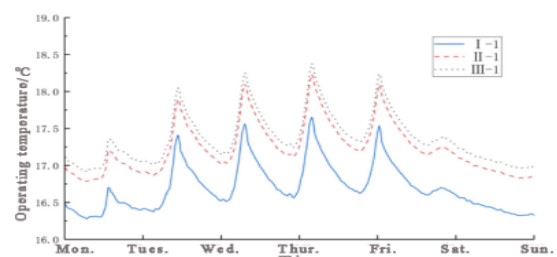


Fig.2. Comparison between simulated data and measured data

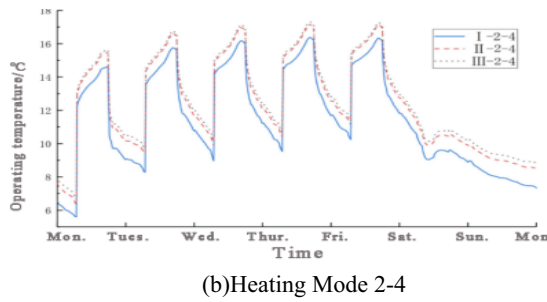
3 Results and discussions

3.1 The influence of envelope structures on indoor thermal environment

Fig.3(a) shows the indoor operating temperature of different envelope structures under continuous heating mode. It can be seen that the indoor operating temperature of type I envelope structure is 0.5 °C and 0.6 °C lower than that of type II and type III envelope structure, respectively. As the indoor air temperature is controlled at the same value, the difference in operating temperature depends on the difference in the average indoor radiation temperature, that is, the change of the wall temperature of different types of envelope structure with the change of outdoor environment. Fig. 3(b) shows the indoor operating temperature of buildings with different enclosures under the same intermittent heating mode. The indoor operating temperature fluctuates greatly under the three enclosures, with the lowest indoor operating temperature falling to 5.7 °C and the highest reaching 17 °C in a typical week. The main reason is that under the intermittent heating mode, the building stops heating at night, and the indoor temperature is greatly reduced after the heating is stopped. The indoor operating temperature of type I envelope structure was 0.8 °C and 0.9 °C lower than that of type II and type III envelope structure, respectively.

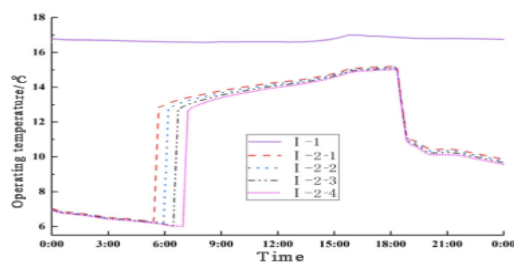


(a) Heating Mode 1

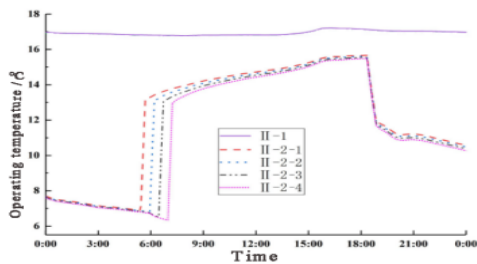


(b) Heating Mode 2-4
Fig.3. Changing in operating temperature of different envelope structure during a week

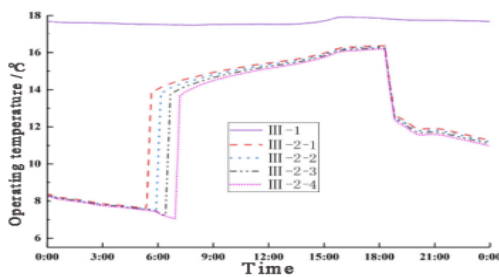
3.2 The influence of heating mode on indoor thermal environment



(a) envelope structure I



(b) envelope structure II



(c) envelope structure III

Fig.4. Changing in operating temperature of different heating modes during a day

Fig.4 shows the variation of indoor operating temperature under type I, II and III enclosures respectively. It can be seen that when the enclosures are the same, the fluctuation trend of indoor operating temperature under the four intermittent heating modes is the same and greatly different from that under the continuous heating mode. Pick a day in a week, the lowest operating temperatures to 5.7 °C, the highest operating temperature is 16 °C. By comparing the variation trend of operating temperature under the four intermittent heating modes,

the indoor operating temperature rose first when the preheating was earlier and remained at the maximum value throughout the whole day under the four intermittent heating modes, and the hourly difference of operating temperature between the four modes gradually decreased with the extension of the heating time. After 18 o'clock, the operating temperature decreased rapidly in each mode, but the operating temperature of scheme III -2-1 was still slightly higher than that of other schemes.

3.3 Energy consumption and energy saving rate of different heating schemes

Table 3 shows the heating energy consumption of the whole building during the kindergarten heating period of the 15 selected heating schemes. It can be seen from the table that with the improvement of thermal performance of the envelope from left to right and the shortening of the heating time from top to bottom, the heating energy consumption of the whole building gradually decreases. Fig. 5 shows the annual heating energy consumption of the whole building for 15 heating schemes, and Fig. 6 shows the energy saving rate of each heating scheme compared with scheme I -1. It can be seen from Fig. 5 that the heating energy consumption of type I envelope is much higher than that of type II and type III under both continuous and intermittent heating modes. In continuous heating mode, the energy saving rate of type II and type III envelope compared with type I envelope is about 29% and 33% respectively. In intermittent heating mode, the energy saving rate of type II and type III envelope compared with type I envelope is about 40% and 48% respectively. For the same envelope structure, that is, any line in Fig. 6, the slope of the first three points is large, indicating that the intermittent heating mode has a great improvement in energy saving rate compared with continuous heating, up to about 35%. The slope of the last four points is small, indicating that the shortening of preheating time has little influence on the improvement of energy saving rate.

Table 3. Annual heating energy consumption of kindergarten

Heating mode		Type of envelope structure		
		I	II	III
1	Heating energy consumption (GJ)	5436.69	3975.25	3717.05
2-1		3654.02	2107.60	1792.37
2-2		3508.55	2069.61	1757.45
2-3		3357.69	2025.36	1716.25
2-4		3201.80	1976.29	1670.77

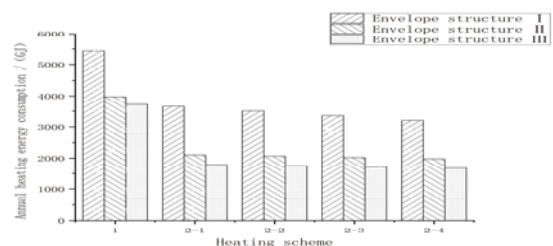


Fig. 5. Heating energy consumption of each scheme

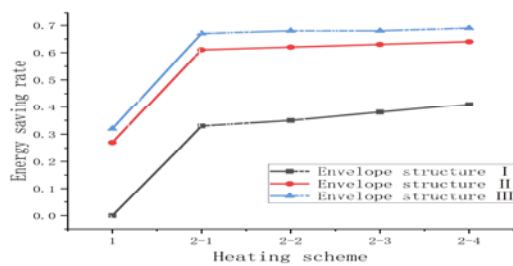


Fig.6. Energy saving rate of each scheme compared

4 Conclusions

Through simulation analysis of the changes in operating temperature and heating energy consumption of typical rooms in kindergarten buildings under different envelope structures and different heating methods, energy saving benefits are calculated, and the main conclusions are as follows:

(1) Optimizing the structure of the envelope and increasing the thickness of the insulation layer are conducive to increasing the operating temperature and improving indoor thermal comfort.

(2) In the intermittent heating mode, the building stops heating at night, and the indoor temperature decreases greatly after the heating stops, making the operating temperature in the intermittent heating mode always lower than that in the continuous heating mode. However, with the extension of preheating time, the operating temperature rises.

(3) Shortening of preheating time has little influence on improving energy saving rate, and the preheating time can be appropriately prolonged to improve thermal comfort.

(4) After energy saving transformation, the total heating energy consumption of the kindergarten building can be reduced by up to 3644 GJ, and the energy saving rate reaches 67%.

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