Numerical study on the influence of insulation position on energy consumption under intermittent heating room

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Abstract. The most commonly used way of heating devices is “part-time and part-space” in hot summer and cold winter zone. In order to explore the energy-saving effect of using inside and outside insulation location for external walls under this heating method, the load characteristics and heat transfer characteristics of intermittent heating rooms with different outdoor temperatures and insulation location are simulated by numerical study. The results show that there is a critical heating duration when the more energy-saving insulation method is selected for intermittent heating buildings. When the operation duration of heating device is less than the critical value, the internal insulation wall is more energy saving. While the outside insulation of external wall has a better energy-saving effect with a heating duration longer than critical value.

Keywords: critical heating duration; heat transfer characteristics; configuration of external wall; energy efficiency.

1. Introduction

The indoor air temperature is low in Hot summer and cold winter (HSCW) zone. Residents generally adopt intermittent heating mode to improve the thermal comfort level [1], which makes the energy consumption of heating devices in residential buildings of this area increase rapidly [2]. There are many studies [3-5] on energy-saving insulation schemes of intermittent energy buildings at present, but those only focus on one-dimensional heat transfer of external walls. It is concluded that the internal insulation has a more energy-saving effect than external insulation. However, due to the partition of the floor and other inner walls in the internal insulation mode, there is a gap between the insulation layers to generate three-dimensional thermal bridge heat transfer [6]. Therefore, the indoor heat is more easily transferred to the outdoor through the thermal bridge of the internal wall. Some studies [7, 8]have performed on the heating load of thermal bridge. All the results showed that comprehensive influence of heat transfer in thermal bridge on heating energy consumption can reach about 30%. However these studies are carried out under the continuous heating mode.

A comprehensive analysis of the influence of heat transfer from external wall and heat bridge is required to achieve the energy saving advantages of internal and external thermal insulation in intermittent heating buildings. Therefore, the method of numerical simulation is carried out to study the effect of heating duration on external wall heat transfer load and thermal bridge heat transfer load under different outdoor temperatures in this paper. The appropriate location of external wall insulation layer of intermittent heating room is obtained by comparing the relative size of the two load.

2. Model setup and study cases

2.1 Model setup

The internal dimension of the model prototype is 4 m (L) × 4.3 m (W) × 2.7 m (H), and the area of the room is 17.2 m^2. The study room is situated at the middle floor of the building, as shown in Fig. 1.

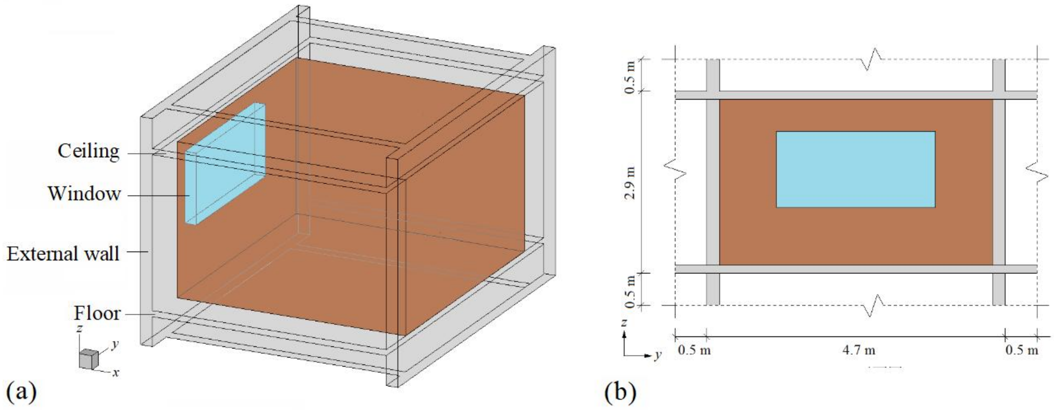

Fig. 1 Schematic diagram of the study room: (a) three-dimensional of the investigated model room, (b) plane y-z of the model

There is a double glazing window with an area of 2.5m × 1.2m at the outside wall. The structural layer of the external and internal wall are 0.2m reinforced concrete. The thermal insulation material is 0.035m extruded polystyrene board (XPS), which is laid on the inner or outer side of structure layer of external wall, respectively. The ceiling and floor are made of reinforced concrete with thick of 0.1m. Furthermore, all the walls are plastered with 0.015m cement layer on two sides. Thermal properties of the aforementioned construction materials are summed up in Table 1.

Table 1. Thermo-physical properties of building construction material.

Material	Reinforced concrete	XPS	Glass	Indoor air	Cement layer
λ [W/(m·°C)]	1.54	0.03	0.76	0.0259	1.74
ρ (kg/m^3)	2400	28	2500	1.205	2500
c [J/(kg·°C)]	840	1380	840	1005	920

The indoor air temperature of study room and adjacent room is 20 °C during the heating duration. In the no-heating time, the temperature of indoor air drops due to heat transfer of the wall. C language programming is used to write outdoor temperature change program. For simplifying the calculation, only radiation of short wave of the outer surface in external wall is considered. While, the radiation of long wave between external wall and sky and surrounding objects is ignored. The numerical aspects and model validation can be seen in literature [9].

2.2 Study cases

The research object of this paper is Shanghai residential building talent apartment and the heating equipment adopts intermittent operation mode. The specific heating duration is shown in Table 2.

Table 2. Cases of heating duration.

Case	Heating duration (h)	Operation time	Behavior characteristics of residents
Case1	3	19:00~22:00	Turn off heating devices before bedtime.
Case2	7	19:00~02:00	Air conditioning timing and automatic

			off after sleep.
Case3	12	19:00~07:00	Air conditioning stays on at night and is turned off before work in the next day.
Case4	17	19:00~12:00	Opening from evening to next morning on holidays.

China Meteorological Data Sharing Service network was used to make statistics on outdoor air temperature in Shanghai from 2015 to 2020. In this study, 2 °C and -2 °C were taken as the lowest outdoor air temperature respectively, and the daily temperature range fluctuated at 8.5 ° C throughout the day. In the following sections, $T_{e,min}$ = 2 °C and $T_{e,min}$ = -2 °C are used, respectively.

3. Results and discussion

3.1 Variation of thermal transmission load of external wall

In this paper, thermal index[9]is used to analyse the load characteristics caused by the thermal transmission of outer wall. Fig. 2 shows the exterior wall thermal indexes qi,e under different outdoor air temperature.

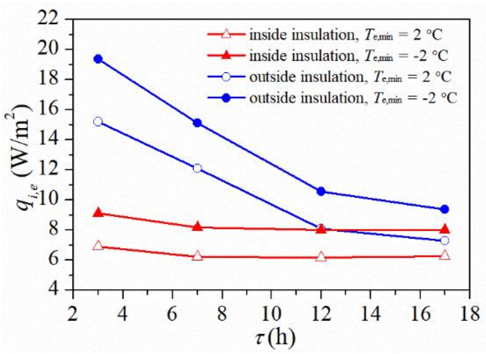

Fig. 2 Variation of exterior wall thermal index under different outdoor air temperature

It can be seen from Fig. 2, for external wall with outside insulation, the wall heat index with outdoor temperature $T_{e,min}$= -2 °C is about 3 W/m^2 higher than that with $T_{e,min}$ = 2 °C. It indicates that the lower temperature of outside air is, the higher heat index of external wall is. With the outside air temperature of $T_{e,min}$= -2 °C, the external wall thermal index $q_{i,e}$ decreases from 20 W/m^2 for 3 h heating duration to 10 W/m^2 for 17 h heating duration. The difference of wall heat index of external wall with inside insulation under different heating duration is not large, which basically maintains at 7 W/m^2.

In order to see the difference of exterior wall thermal index caused by types of thermal insulation under different outdoor temperature clearly, the heat index difference between external wall with internal and external insulation $q_{i,e}$' is defined as:

$$q_{i,e}{}' = q_{i,e/outside} - q_{i,e/inside} \quad (1)$$

where, qi,e,outside is the heat index of external wall with outside insulation, W/m2; qi,e,inside is the heat index of external wall with inside insulation, W/m2.

Fig. 3 shows the qi,e' under different outdoor temperature and heating durations, taking the fourth day as an example.

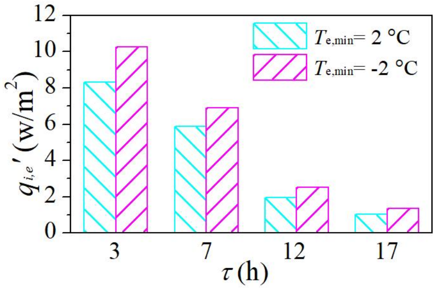

Fig. 3 Variations of $q_{i,e}'$ with heating duration under different outdoor temperature

It can be seen from Fig 3 that $q_{i,e}'$ decrease obviously as the heating duration increases. When the heating duration increases from 3 h to 17 h, $q_{i,e}'$ decrease from 10.6 W/m^2 to 1.1 W/m^2 with the outdoor temperature fluctuating with $T_{e,min}$= -2 ° C. This shows that in terms of the thermal transmission load of external wall, external wall configurated with inner insulation has obvious energy-saving advantages under short heating duration. The energy conservation advantage of external wall with inner insulation is significantly reduced for long heating duration.

3.2 Analysis of the thermal transmission load of internal wall

According to the heat convection between the inner surface of the internal wall and the indoor air, the heat index of the internal wall is calculated. Fig. 4 indicates that the thermal indexes of internal wall vary under different outdoor air temperature.

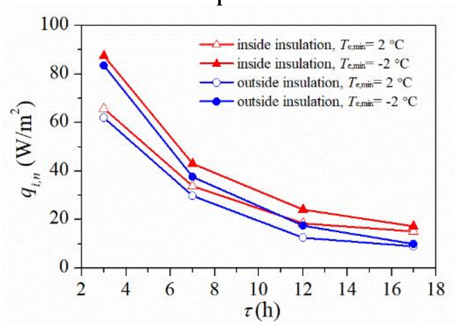

Fig. 4 Internal wall thermal indexes vary under different outdoor air temperature

It can be seen from Fig.4 that under the mode of internal insulation, the thermal index of the internal wall with $T_{e,min}$= - 2 °C is obviously larger than that with $T_{e,min}$=2 °C, but the difference between the two decreases with the heating duration increases. With the heating duration of 3 h, the difference between them is 16.5 W/m^2. While, when the heating duration increases to 17 h, the difference between them decreases to 4.01 W/m^2. This indicates that as the heating duration increases, the influence of different outdoor temperatures on the heat index of the inner wall gradually decreases.

For comparing the increment of the heat index of the internal wall caused by thermal bridge of the internal insulation under different temperature of outdoor air, the difference of the heat index $q_{i,n}'$ of the internal and external insulation is defined:

$$q_{i,n}' = q_{i,n/outside} - q_{i,n/inside} \quad (2)$$

Figure 5 shows the variation characteristics of heat index difference $q_{i,n}'$ of internal wall between internal and external insulation under different heating duration.

It can be seen from Figure 5 that with the increase of heating duration, the difference of internal wall heat index $q_{i,n}'$ gradually increase under different insulation types. When the heating duration increases from 3 h to 17 h, the absolute value of $q_{i,n}'$ increases from 4.25 W/m^2 to 7.63 W/m^2. This shows that under a longer heating duration, the heat index of the internal wall is smaller when the external insulation is adopted.

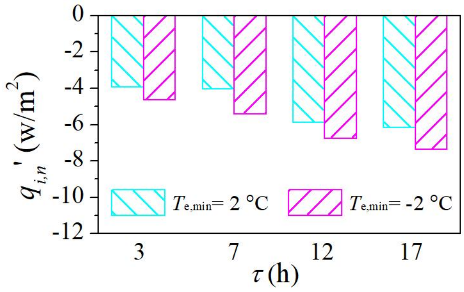

Fig. 5 Variation characteristics of heat index difference $q_{i,n}'$

By contrasting Fig. 3 and Fig. 5, it is apparent that the heat index difference of external wall $q_{i,e}'$ and internal wall $q_{i,n}'$ under different insulation methods show an opposite trend as the heating duration increases. To make a comparation between the heat index difference of external and internal wall under different insulation methods more conveniently, Figure 6 summarizes the changes of the two along with the heating duration.

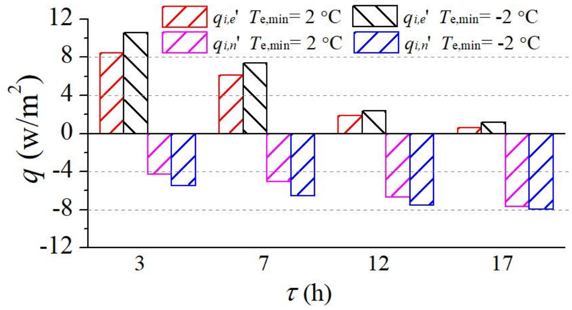

Fig. 6 Variation of $q_{i,e}'$and $q_{i,n}'$ with heating duration

It is can be seen obviously in Fig. 6 that the difference values of external wall thermal index $q_{i,e}'$ decrease with the increase of heating duration under different insulation types. While, the absolute value of the thermal index difference $q_{i,n}'$ of the inner wall increases as the heating duration increases. The opposite trend leads to the existence of critical heating duration when the intermittent heating buildings choose more energy-saving insulation methods. When it comes to the heating duration less than 7 h, the sum of $q_{i,e}'$and $q_{i,n}'$ is greater than 0. It indicates that for external wall with internal insulation, the sum heat index of external wall and internal wall is lower than the external wall with outside insulation. When the heating time is greater than 7 h, the sum of $q_{i,e}'$and $q_{i,n}'$is less than zero. It indicates that the thermal index of external wall and internal wall under insulation placing on the outside of external wall is smaller than that placing on the inside.

4. Summary

In the present work, numerical simulation method is performed to illustrate the effects of insulation location on the heat transmission characteristics of thermal bridge and walls under intermittent heating durations. The main conclusions are presented as follows:

(1) In the short heating duration(less than 7 h), placing the insulation on the inside of external wall is more energy-saving than that on the outside. However, with the heating duration increase, the energy-saving method is opposite.

(2) Moreover, the existence of critical heating duration when the intermittent heating buildings choose more energy-saving insulation methods. In this study, the critical heating duration is between 7 h and 12 h under the outdoor temperature condition.

(3) Internal wall with inside insulation is obviously affected by the heat transfer of thermal bridge than that with outside insulation. Meanwhile, the lower the outdoor temperature and the longer the heating duration, the more serious the influence of the thermal bridge on internal wall.

Acknowledgment

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