A Study of the Impact of Interior Envelope Structure on Cold and Hot Load in Yangtze River Basin of China

Xiaofang Deng, Wei Yu and Xiangzhong Meng

Abstract The climate in the Yangtze River basin in China is hot in summer while cold in winter, and humid yearly. The operation mode of heating and air-conditioning of residential buildings in this region is intermittent and air conditioners are used in the part of rooms. Most of the existing researches focus on the design of external envelope structures such as external wall, roof, external window, and natural ventilation of air infiltration. Little research paid attention to the impact of interior envelope structure on HVAC energy consumption. For this purpose, this paper did a literature review of the research toward interior envelope structure. Then a typical building model was selected according to the questionnaire survey results and relevant standards. The impact of interior envelope structure on heating and air-conditioning load and the heat transfer energy of each surface of room were discussed by simulation software EnergyPlus. With the analysis, this paper proposed that heat transfer through interior enclosure and the operating performance of air conditioner between rooms which have different operating schedules and temperature settings should be emphasized and finally indicated the further work.

Keywords Yangtze River basin · Interior envelope structure · EnergyPlus · Heat transfer energy

1 Introduction

The Yangtze River basin is vast and densely populated. With the development of the economy, the number of the building increases rapidly in this area. According to incomplete statistics, the total building of the Yangtze River basin has reached 24 billion 500 million square meters in 2015, 20% of which is the public building

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while the urban residential area accounts for about 40%. However, the climate in this area is hot in summer, cold in winter, and humid throughout the year. The thermal performance of the building enclosure is not good, which could lead to a bad indoor thermal environment. People are eager to improve the indoor thermal comfort environment.

In order to improve the indoor thermal and humidity environment and reduce the energy consumption of heating and air-conditioning, there are many researches aiming at energy-saving design. Ya et al. [1] found that reducing the heat transfer coefficient of the enclosure structure in southern China, especially in the hot summer and cold winter areas, is beneficial to reduce the energy consumption of the heating in winter and to reduce the energy consumption of the air-conditioning in summer. However, both in winter and in summer, improving the thermal stability of the enclosure structure is beneficial to improve or reduce the interior surface temperature of the external wall, effectively delay and attenuate the effect of outdoor temperature wave.

Some studies investigate the adaptability of external thermal insulation, internal thermal insulation, and self-insulation in Chongqing and Changsha areas by simulation and experiment [2–4]. With the analysis, it is confirmed that the external thermal insulation effect of this area is better than that of other thermal insulation effects. But some research shows that external thermal insulation has the characteristics of reverse energy saving [4–6]. Some studies [7, 8] analyze the sun shading of this area. It is concluded that the sun shading measures in the area should be focused on the West windows and the South windows. Some researchers study [9, 10] the natural ventilation in this area, and it is concluded that the ventilation potential in the night ventilation and the transition season is great, and making full use of natural ventilation can greatly improve the indoor heat and humidity environment. In addition to the single optimization analysis of the passive design of the building, other studies [11–14] optimize the design parameters of the thermal performance, sunshade, and ventilation of the external enclosure structure by using the optimization design method and get the energy saving design strategy of various regions.

However, due to the climate characteristics of this region, the using mode of the heating and air-conditioning is "part of space and intermittent time." "Part of space" is using air conditioning only in some rooms not in all rooms of a house. And this mode leads to the result that not only outdoor thermal environment, but also indoor thermal environment of the room affects indoor thermal environment and energy consumption. The characteristics of "intermittent time" are people use air-conditioning discontinuously, indoor thermal environment changes greatly, especially in winter, which can bring discomfort to the residents. The above literature basically optimizes the thermal performance, sun shading, and ventilation of the outer enclosure. It focuses on the passive optimization strategy of the building external envelop structure and neglects the influence of the interior envelop structure on the indoor thermal environment and the energy consumption of the heating air-conditioning.

Based on the characteristics of "part of space and intermittent time" heating and air-conditioning mode in the Yangtze River basin, the influence of interior enclosure structure on energy consumption of heating air-conditioning is studied, and it is important to optimize the interior enclosure structure.

2 Methods

2.1 Model Description

This study is focused on the numerical method of simulating the heat and cold load and the heat transfer energy. A simulation software EnergyPlus is used. A typical residential house locates in Chongqing of China with a height of 3 m and 11 floors and is confirmed as the experimental residential building by questionnaire survey results and relevant standards (Fig. 1). The materials of this building are provided by the most commonly used building materials in this area (Table 1). To ensure that the simulation results are only related to the enclosure structure, the indoor thermal disturbance is not set, the air-conditioning temperature is set at 26 °C in summer while 18 °C in winter. The weather parameter of the selected city can be obtained by the EnergyPlus Web site.

In order to investigate the impact of interior envelope structure on heating and cooling load, three building models are established, which include a building without any interior envelope structure, a building without a partition wall, a building with all interior envelope structure (Fig. 2). The heating and cooling loads of design days on January 21 and July 21 are selected as analysis data.

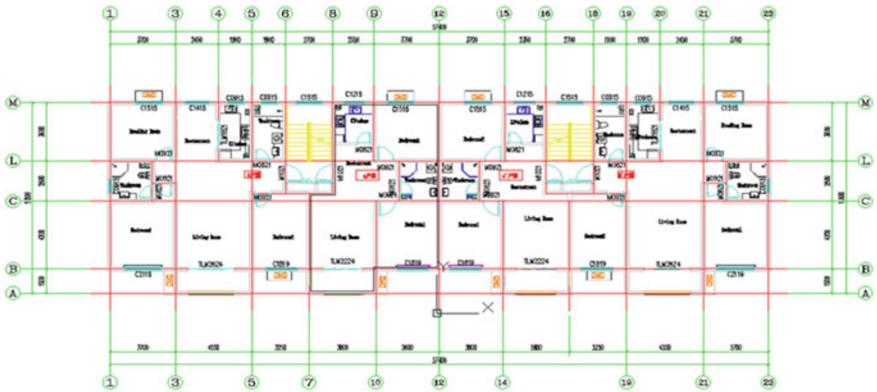

Fig. 1 Model layout

Table 1 Basic structure of a typical building

	Structure	Heat transfer coefficient W/(m^2 K)
External wall	Cement mortar 20 mm + sintering perforated brick of shale 200 mm + difficult flammable polystyrene board 30 mm + cement mortar 20 mm + anti-crack mortar (gridding cloth) 5 mm	1.0
Interior wall	Cement mortar 20 mm + shale cavity brick 200 mm + cement mortar 20 mm	1.65
Roof	Macadam and pebble concrete 20 mm + cement mortar 20 mm + difficult flammable extruded polystyrene board 35 mm + SBS modified asphalt waterproofing membrane 5 mm + cement mortar 20 mm + sintering haydite concrete 1551–1650 30 mm + reinforced concrete 120 mm	0.76
Window	6 high transmittance Low-E + 12 A + 6	2.4 (Self-shading coefficient of 0.7)
Window-wall ratio	South ratio = 0.3, east and west ratio = 0.15, north ratio = 0.3	

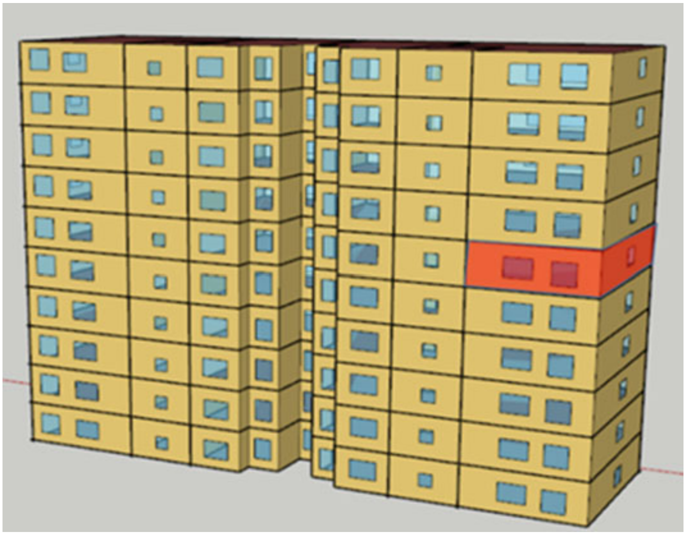

Fig. 2 Building model

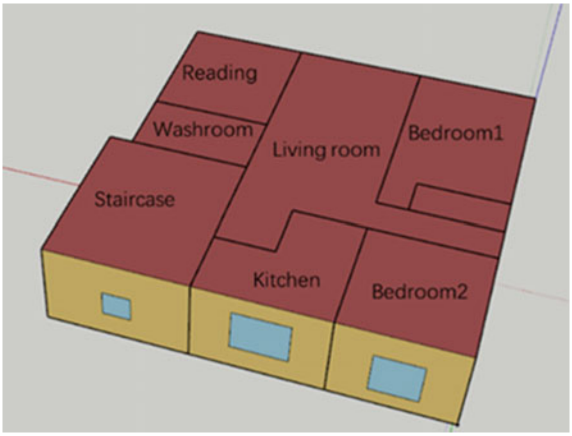

Fig. 3 Household for heat transfer model

2.2 *Heat Transfer Model*

The heating and cooling loads caused by external enclosure structure are due to the difference in temperature between indoor and outdoor. Another important factor is the thermal storage of enclosure structures. Due to the "part of space and intermittent time" mode of energy consumption in the Yangtze River basin, different rooms have different space and time on using air conditioners. As a result, there is a temperature difference between the rooms, and there will be heat storage of interior envelope structure. To explore the impact of interior envelope on the room, a household of the previous model is selected to investigate the transfer energy of every surface (including external wall, external window, partition wall, interior ceiling, and interior floor) of a room (Fig. 3).

3 Results

From Fig. 4, it can be seen that the heating and cooling loads of the building with interior enclosure structure are more than the building without interior enclosure structure in winter and summer, and the more the interior enclosure structure is, the load is much larger, especially in the cold and heating seasons.

From Fig. 5, it can be seen that there is a large temperature difference between the living room and the bedroom during the heating and air-conditioning time from 23 pm to 7 am the next day. In winter, the heat transfer is negative while the heat storage is positive. In summer, the heat transfer is positive while the heat storage is negative. This shows that during the winter heating time, the bedroom temperature is greater than the living room temperature, heat transfers from the bedroom to the living room. With the heating time going by, the heat storage capacity gradually decreases. Similarly, during the summer cooling time, the heat comes into the bedroom from the

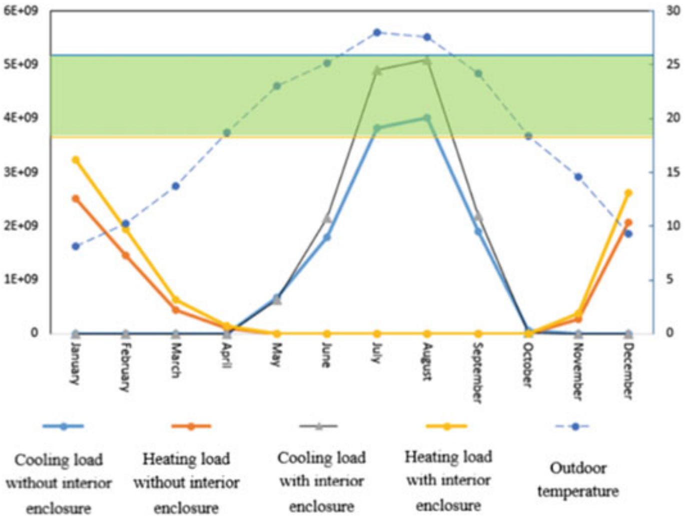

Fig. 4 Heating and cooling load of the building with or without an interior enclosure

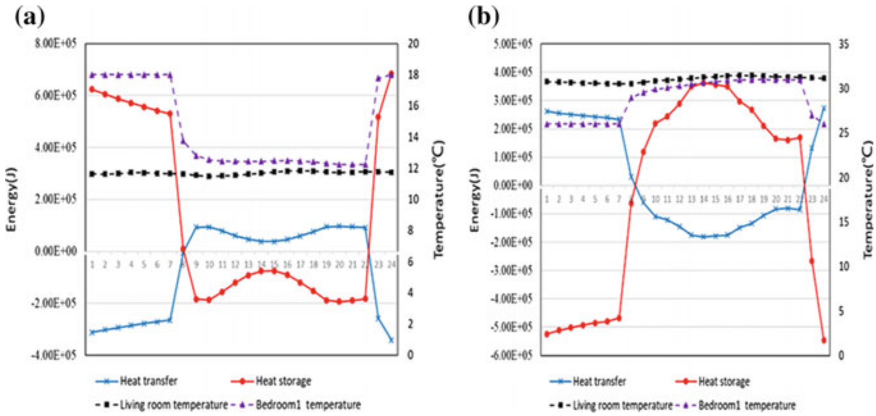

Fig. 5 **a** Curve of the heat transfer and temperature of an interior wall between the living room and the bedroom 1 of winter design day. **b** Curve of the heat transfer and temperature of an interior wall between the living room and the bedroom 1 of summer design day

living room, and the heat stored in the wall during the day is released in the evening, resulting in the more cooling load at night.

From Fig. 6, it can be seen that in winter from 10 pm to the next day 7 am air-conditioning operation stage, heat transfers through internal and external enclosure structure to indoor. During the non-air-conditioning heating stage, except the roof, heat transfers through other interior and external enclosure structure into the room. During the daytime, the indoor heating capacity of the external protective structure is

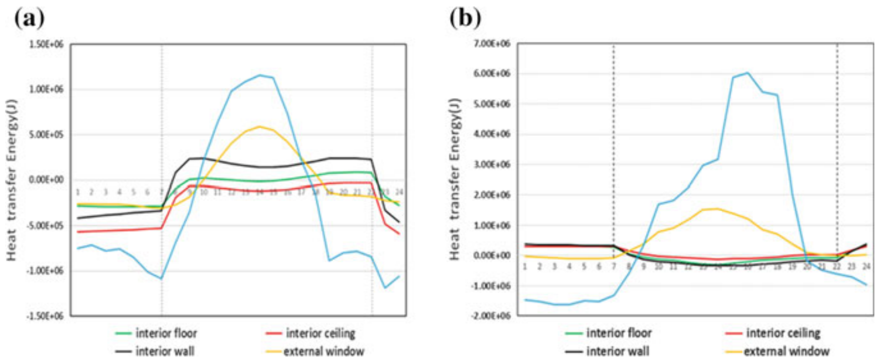

Fig. 6 **a** Heat transfer of every surface of bedroom 1 during winter design day. **b** Heat transfer of every surface of bedroom 1 during summer design day

larger than that of the external enclosure structure, and the crest appears at noontime, while the internal enclosure structure is stable. The heat consumption of the external wall and roof is the main part of winter, and the heat consumption of the roof is the largest. During the heating time, the total heat consumption through the internal enclosure is greater than the external structure. During the summer air-conditioning operation stage, the heat is lost through the external enclosure structure while during the non-air-conditioning time heat enters the room, causing the accumulation of heat in the room. No matter during the day or night, heat enters the air-conditioned room through the internal envelope, resulting in the cooling load. Table 2 shows the proportion of heat consumption under different enclosure structures.

S is the proportion of each part of the enclosure structure's area to the whole room enclosure structure's area, and *T* is the proportion of each part of the enclosure structure's energy consumption to the whole room energy consumption. As it can be seen from Table 2, although the heat transfer of the external enclosure structure is higher than the internal enclosure structure, the heat transfer area of the internal enclosure structure in a room is greater than that of the external enclosure. For example, the proportion of heat transfer area of the living room accounts for 91.68% of the total heat transfer area in the room, and the heat transfer accounts for 82.29% of the total heat transfer. It shows that the interior enclosure structure in the intermittent air conditioning mode has a high degree of heat transfer, and the capitalized "S" is,

Table 2 Heat transfer energy of different enclosure structure

	External window (%)	External wall (%)	Interior wall (%)	Interior ceiling (%)	Interior floor (%)
	S/*T*	*S*/*T*	*S*/*T*	*S*/*T*	*S*/*T*
Bedroom 1	2.8/11.17	22.81/38.36	32.54/15.93	20.92/23.03	20.92/11.51
Bedroom 2	3.94/13.66	26.07/38.66	30.01/15.34	19.99/21.14	19.99/12.21
Living room	2.59/5.58	5.73/12.14	47.78/37.80	21.95/31.72	21.95/12.77

the greater the influence on the heating and air conditioning load of the room is. It can be seen that when the external enclosure structure meets the design requirements of the relevant energy-saving standards, the interior enclosure structure has great energy-saving potential in this "part of space and intermittent time" using mode.

4 Conclusions

The impact of interior envelope structure on heating and cooling load in Yangtze River basin of China is studied. An energy simulation strategy is created for a typical household model. In this experimental case, the heating and cooling loads and the heat transfer energy of every surface of a room are simulated. From the analyses, it is concluded that under the heating and air-conditioning mode in part of the space, the more heat transfer area of the inner envelope, the greater the heat consumption through the inner envelope. In winter, in the air-conditioning operation stage, due to the lack of heating in the temporary room, the heat is dissipated from the air-conditioned room through the inner and outer enclosure structures. In summer, heat is transferred from non-air-conditioned rooms and outdoor buildings to air-conditioned rooms by internal envelope and external envelope, resulting in increasing cold load; in night, the heat from the air-conditioned room through the outer enclosure structure to the outdoor, from the non-air-conditioned room through the inner envelope to the air-conditioning room, causing cold load at night.

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