Effect of the thermal insulation wall under the air-conditioning intermittent operation

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Abstract. With the increasing energy consumption, the status of building energy conservation is paid more and more attention. So how to reduce the energy consumption of envelope becomes a hot spot. Self-insulation wall behaves greatly in energy saving, and this paper proposes a self-insulation wall which is filled Expanding Polystyrene(EPS) into the cavities of the sintered shale bricks with different ration. Besides, the condition of intermittent operation of air conditioner in winter is simulated. The results showed that temperature of the wall increased significantly after filling the EPS, and the wall had a good thermal insulation performance. The thermal insulation wall with 50% EPS is recommended, no matter from the aspect of the economy or of thermal physics. Moreover, intermittent operation which is 1 hour interval and 1 hour working was the idealist mode, because the wall performed the best capacity of insulation under this condition.

1. Introduction

Saving energy has a profound effect on people’s development. In China, the biggest part energy consumption in building is caused by the external protection structure[1], so the exploration and innovation of energy saving technology in walls has been widely investigated. Thermal insulation is one of the most effective ways of energy saving[2-3].

Intermittent operation is a way that makes it possible to maintain the indoor temperature and achieve reduction in electricity demand[4], which achieves the goal of saving energy. Meral Ozel[5] investigated insulation location and thickness in walls, the results showed that insulation location has a great effect on yearly averaged time lag. Besides, the maximum temperature swings and peak load in both summer and winter occur in the case that insulation is placed at the middle of wall. For intermittent operation of air conditioner, many studies have been conducted to investigate the insulation location and wall orientations. Lili Zhang[6] studied the thermal insulation layer location on wall dynamic thermal response rate under the air-conditioning intermittent operation. It was found that the wall internal layer has the significant effect on the wall dynamic thermal response performance. Xi Meng et al.[7] studied the different forms of insulation wall under the intermittent operation in summer, and concluded that those walls have a significant impact on the temperature response rate and internal surface heat flow under the intermittent operation of air conditioner. Indoor thermal insulation is more suitable for the intermittent operation.

At present, filling insulation layers into the inner or outer surface of a wall is generally applied. The fact is that the secondary construction and installation of insulation layers not only increase the construction cost, but also delay the construction time[8-9]. But filling insulation materials into the
cavity of bricks overcomes the two disadvantages mentioned above. Zukowski[10] researched the thermal properties of hollow brick which was filled with perlite insulation and their results showed that heat conductivity of this brick can be equal to 0.09W/(m·K), which revealed the high insulation property. Quanbiao Xu et al.[11] found the thermal performance of sintered shale hollow block can be greatly improved through filling the expandable polystyrene board. The autoclaved sand aerated concrete block performed obviously better than other wall materials. It is a kind of self-insulation material especially suitable for hot summer and cold winter areas. Hou[12] explored a wall filled with EPS, and concluded that filling EPS in cavities is beneficial to improve the thermal performance. The larger the EPS filling ratio is, the higher the thermal performance improved. Guibing Li[13] found that solid brick walls composed with 50 mm thick EPS board on their outside surfaces can reduce the hourly heat transfer about 67.5% and it has a good heat stability which is benefit for building energy conservation and the operation and control of heating equipment.

From the above review, this paper chose EPS as the insulation materials, and the insulation wall will be under intermittent operation. Six kinds of insulation walls are established: the EPS board is filled into the brick holes with different position and filling rate. And this experiment uses Heat Flow Meter method combined with a box, which can measure the inside, outside temperature and the heat flow on the inner surface. Eventually we analysed the performance of the six kinds of insulation walls by heat transfer coefficient.

2. Experimental system and model.

2.1. Experimental system

As one of the green building materials, sintered shale porous bricks are vigorously promoted to use as the foundation for building. It is flexible and simple in design, cost effective, widely available materials. Last but not the least, it has good sound insulation and thermal insulation effect[14-15]. In this paper, eight-hole sintered brick is selected.

The form of the brick is shown in Figure 1. The size of the brick is 240mm×190mm×110mm, and the size of the hole is 35mm×40mm.

The filling material selected is Expanded Polystyrene board (EPS insulation board), because it’s flame retardant, low costing and thermal insulated[16]. EPS insulation boards are chosen to fill the holes in the bricks and fill the gaps in the hot and cold box. In this study, six ways of filling are as follows: 1) no EPS insulation material is filled (the first row); 2) 25% EPS insulation material is filled, and one side (the second row) is filled near the room and the other side (the third row is filled near the middle; 3) filled with 50% EPS insulation material: one side of the concentrated filling (the fourth row) and on both sides of the filling (the fifth row); 4) filling rate is 100% (the sixth row). The different bricks are shown in Figure 2.
2.2. Wall model and equations

This paper uses the Heat Flow Meter method (HFM) [11]. The experimental box is composed of hot and cold chambers, hot box which simulates the indoor environment is set to 25 °C, and cold box which simulates outdoor environment is set to 0 °C. The indoor temperature $T_1$, heat flow and hot temperature $T_2$ are recorded by multi-channel temperature heat flow meter. The specific details are shown in Figure 3. The equations are used to calculating thermal resistance and heat transfer coefficient, as shown in equation (1) and (2)

$$K = \frac{1}{R_i + R + R_e}$$  \hspace{1cm} (1)

$$R = \frac{T_2 - T_1}{H}$$  \hspace{1cm} (2)

- K - heat transfer coefficient, W/(m²·K);
- R - thermal resistance of the measured object;
- $T_1$ - cold end temperature, °C;
- $T_2$ - hot end temperature, °C;
- H - heat flow meter reading, W/m²;
- $R_i$ - Inner surface in thermal resistance, (m²·K)/W; take 0.11 (m²·K)/W in engineering practice;
- $R_e$ - outer surface heat resistance, (m²·K)/W, take 0.04 (m²·K)/W in engineering practice;

To enclosure structure, the smaller the heat transfer coefficient is, the better the wall insulation performance will be.

The time arrangement and simulation experiment of air conditioner are shown in Table 1.
### Table 1. The time arrangement of simulation experiments

| Test number | Date      | Working time(h) | Intermittent time(h) |
|-------------|-----------|-----------------|----------------------|
| 1           | 2019/2/27 | 1               |                      |
| 2           | 2019/2/28 | 2               |                      |
| 3           | 2019/3/1  | 0.5             |                      |
| 4           | 2019/2/27 |                 |                      |
| 5           | 2019/3/2  | 1               | 2                    |
| 6           | 2019/3/3  |                 | 0.5                  |
| 7           | 2019/2/26 | 0.5             | 0.5                  |
| 8           | 2019/2/27 | 1               |                      |
| 9           | 2019/3/4  | 2               | 2                    |

### 3. Experiment results and analysis

#### 3.1. Comparison of temperature

The temperature of the inner surface rose rapidly when the hot box started to work. After stopping running the box, the temperature remained flat or continued to rise. The results of test 1-3 are shown in Figure 4, Figure 5 and Figure 6. The outer surface temperature dropped significantly when cold box began to work. When the experimental box stopped working, the temperature rose immediately. After the experiment box ran again, inner temperature had a slight decline or flat trend, and outer temperature had a sharp rise, this is because outer surface temperature is low and the inner surface temperature is high, so that heat transfers spontaneously from high-temperature side to low-temperature side. We can easily see that the inner temperature decreased slightly while the increase of the outer temperature is obvious. Hence, the walls have a good function in insulation. From the six pictures, the wall temperature from high to low in turn is: the sixth row (100%), air temperature, the fifth row (50%), the forth row (50%), the third row (25%) the second row (25%), and the first row (0%). It shows that the wall temperature is proportional to the filling rate. The more EPS thermal insulation material is filled, the higher the wall temperature will be.

![Figure 4](image4.png)

**Figure 4.** The inner temperature(left) and outer temperature(right) of 0.5h heating with 1h intermitting.

![Figure 5](image5.png)

**Figure 5.** The inner temperature(left) and outer temperature(right) of 1 heating with 1h intermitting.
3.2. Comparison and analysis of heat transfer coefficient

Through the heat flow meter method, we calculated the heat transfer coefficient (K) by equation (1) and (2). The results are shown in Figure 7, Figure 8 and Figure 9.

In the experiment of 0.5-hour heating with 1-h intermitting, we can see that the fifth row (50%) had the smallest K among the six thermal insulation walls, then followed by the sixth (100%), the second (25%), the forth (50%), the first (0%), and the third row (25%). Therefore, in the case of intermittent operation, the fifth row showed the best insulation performance in the way of filling, that is, both sides of the brick are filled with EPS. The result of 1-h heating with 1-h intermitting only differs the best-performance wall from the previous experiment, and the best insulation wall is the sixth row which the filling rate is 100%. The third row was still the worst.

Through heating for 2 hours and intermitting for 1h, the fifth layer shows the smallest K again. The biggest K is the third row again.

To sum up, under the condition of different operating time with the same intermittent time, filled with 50% of EPS into the holes on the either side or fully filled with EPS, the wall had the best thermal insulation performance. However, we suggested the former from the economic perspective. In three cases, the third row, namely the wall filled with 25%EPS, behaved the worst thermal insulation performance. What beyond our expectation is that filling insulation materials may not have the heat preservation effect.
Another group of experiment simulated the air conditioner under the same running time and different intermittent time. We obtained the data and got K by equation (1), (2) running for 1 hour and interrupting for 1 hour has been described.

Experimental results of 1h heating with 0.5h and 2h intermittent have been shown in Figure 10, Figure 11, the K ranked from small to large was the same as the test 2, therefore, the wall with optimal heat preservation is fully filled.

It can be seen from the graphs that the heat transfer coefficient curves of the sixth row (100%) and the fifth row (50%) basically coincided with each other. K of the sixth row was slightly smaller. Still, the third row had the largest K, which means the worst insulation performance.

Hence, the wall of the sixth (100%) and fifth row (50%) show the best insulation performance. The performance of full filling is slightly better and the insulation performance of the third floor is the worst.

Combined with the two groups of experiments, it can be seen that when the heating time is longer than the intermittent time, the heat transfer coefficient is obviously higher, indicating that the insulation performance is worse at this time. In the five tests, the lowest heat transfer coefficient is heating for 1h with interrupting for 1h, so this kind of intermittent operation is the commendatory operation mode for air conditioner. From the perspective of the economy, the way of filling rate of 50% is the best way of external wall self-insulation.
4. Conclusions

In this study, we constructed six walls, using EPS as the insulation materials and filling it into bricks differently, and these walls were under the air-conditioning intermittent operation. So we got the conclusions as follows:

1. After filling EPS insulation into the cavities of brick, the wall temperature was proportional to the filling rate. The higher the filling rate is, the higher the wall temperature will behave;
2. The heat transfer coefficient doesn’t have a positive correlation with the filling rate, instead, it depends on the filling mode and filling rates collectively. In other words, the effect of insulation wall is not proportional to the filling rate.
3. In the experiments of different operation times and the same intermittent time, the wall with 50% EPS(filled into holes on either side) and 100% EPS had the best insulation performance, while the wall with 25% EPS(near the middle hole) insulation materials behaved the worst. Considering the economical factor, we recommend the former to be applied in reality.
4. The intermittent operation of 1h heating with 1h intermitting is the commendatory operation mode for air conditioner.

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