CFD Simulation on Thermal Properties of Ventilation Wall for Various Types of Air Exchange in Cold Regions of China

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Abstract
The urgency of the considered problem is stipulated by lack of natural ventilation upon application of a Trombe wall in winter conditions. This work is aimed at investigation into feasibility of air exchange through a Trombe wall and thermal features of external insulation in cold seasons as well as at searching for the best variants of air ducts for residential buildings in China. This work discusses features of Trombe wall and building insulation with porous screen. Heat and air exchange of solar wall is analyzed using mathematical simulation. Thermal properties of solar wall have been simulated and analyzed with various air ducts. On the basis of the obtained results reasonable sizes of air intake and off-take in solar wall with porous screen are proposed. The results of this work can be applied for implementation of solar wall in residential buildings of cold regions.

Key words: Trombe wall, passive systems, heat and air exchange, air duct, CFD simulation.

1 Introduction
A passive house is the standard of energy efficiency in civil engineering which assumes achievement of optimum balance between energy savings, healthy microclimate and careful attitude to environment. Passive systems of solar heat supply are based on natural circulation of heated air [1-3]. Solar Trombe wall is a passive system of solar heat supply. The wall design permits to accumulated and store solar energy during all solar day and then to release the heat in certain time interval (usually at night) [4-6]. According to the operation principle of Trombe wall ventilation is carried out only in internal space, the quality of surrounding environment decreases due to lack of fresh air.

Despite the fact that Trombe wall decreases thermal load on house heating system in winter, gradual heat release into building in summer creates overheating because solar energy easily passes via glass and is accumulated on wall black surface [7-11]. In order to prevent this disadvantage descending curtains or shutters are used, though, these systems of sunlight protection are inefficient. Hence, it is required to substitute glass screen.

Belyaev and Esengabulov [12-14] developed exterior walls with recovery of transmission and ventilation heat replacing glass in the wall with porous screen. During experiments it was established that in summer conditions the amplitude of temperature oscillations of internal surfaces of exterior wall with vented interlayer decreased by 1.5 times. However, at present theoretical and numerical analyses of heat and air exchange aiming at adjustment of holes in solar walls in winter are unavailable both in Russia and in China. Hence, it is required to develop appropriate mathematical models and to perform technical analysis using numerical simulation in terms of heat and air exchange via holes of air ducts located on solar wall surfaces.

2 Methods
On the basis of previous researches [15] this work was carried out using walls with non-insulating screens with sizes of 1000×2800×150 mm. With consideration for model requirements and mesh partition using ANSYS ICEM CFD wall design structure was simplified, it was comprised of marble screen with thickness of 25 mm, air interlayer in 150 mm, and reinforced concrete in 200 mm, since marble had been characterized by high coefficient of heat absorption. For provision of heat and air exchange as well as for improvement of thermo-technical property of insulation four square holes were located in lower surface portion of external screen, thus arranging heat exchange channel with air interlayer via similar holes in upper portion of main wall (see Fig.1).

The structure of the hollow block ventilation wall

![Fig1: Schematic view of ventilation wall](http://example.com/fig1.png)

Using mathematical analysis, it was proved that themost important items of engineering elements influencing on heat and air exchange of solar wall according to equation of energy conservation were configuration and hole sizes of air intake and off-take [16]. Regularities of heat supply with various hole sizes inlet were studied by numerical analyses using ICEM 15.0 and Fluent 15.0 software under stationary conditions of heat transfer. Climatic parameters for January 22 in Zhengzhou, China were selected in...
Weather Tool ECOTECT software.

It can be seen that sunrise and sunset on January 22 in Zhengzhou take place at 08:00 and 17:00 o'clock, respectively. At 08:00 o'clock the intensity of sun irradiation is very low and does not exceed 300 W/m², and the radiation amount does not provide efficient increase in air temperature in wall collector with account for absorption coefficient of screen. While Sun travels across the sky total amount of radiation reaches its peak of 600 W/m² at 13:00 o'clock, and at the same time the external air temperature is only 10.6°C, the maximum temperature of 11.8°C is reached at 16:00 o'clock due to delayed convective heat exchange. Taking into consideration the aforementioned data, comparative analysis for mathematical simulation was performed for the situations at 08:00, 13:00, 16:00, and 23:00 o'clock; calculated temperature in rooms was 18°C according to SNiP regulations. External screen in wall was made of marble connected to the wall by fastening elements. The wall and the screen had no heat insulation; thermo-technical properties of the wall materials are summarized in Table 1.

<table>
<thead>
<tr>
<th>Structure</th>
<th>Material</th>
<th>Thickness, mm</th>
<th>Density, kg/m³</th>
<th>Thermal conductivity, W/m·K</th>
<th>Thermal capacity, J/kg·K</th>
<th>Absorption coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screen</td>
<td>Marble</td>
<td>25</td>
<td>2800</td>
<td>2.91</td>
<td>0.92</td>
<td>0.8</td>
</tr>
<tr>
<td>Interlayer</td>
<td>Air</td>
<td>150</td>
<td>1.293</td>
<td>0.023</td>
<td>1.05</td>
<td></td>
</tr>
<tr>
<td>Main wall</td>
<td>Reinforced concrete</td>
<td>200</td>
<td>2500</td>
<td>1.74</td>
<td>0.92</td>
<td>0.48</td>
</tr>
</tbody>
</table>

Table 1: Thermo-technical properties of wall materials

An important boundary condition in simulation is determination of equivalent temperature on surface of porous screen resulted from sun irradiation using the following equation [17]:

\[ t_e = t_{ext} + \frac{\rho I}{a_{ext}} \]

(1)

where \( t_e \) is the equivalent temperature from sun irradiation; \( t_{ext} \) is the temperature of external air; \( \rho \) is the coefficient of absorption; \( a_{ext} \) is the coefficient of heat transfer of external surface of insulating structures; \( I \) is the total intensity of irradiation. The determined equivalent temperatures are summarized in Table 2.

<table>
<thead>
<tr>
<th>Time</th>
<th>08:00</th>
<th>13:00</th>
<th>16:00</th>
<th>23:00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air temperature</td>
<td>5°C</td>
<td>10.6°C</td>
<td>11.8°C</td>
<td>0.4°C</td>
</tr>
<tr>
<td>Equivalent temperature</td>
<td>14°C</td>
<td>31.12°C</td>
<td>27.87°C</td>
<td>2.6°C</td>
</tr>
</tbody>
</table>

Table 2: Equivalent temperatures on wall surface resulting from solar irradiation

Air intake mode is selected upon inlet air pressure and air off-take mode is selected at outlet pressure. All holes are opened, the simulation starts at inlet pressure.

3 Results

Thermo-technical properties of Trombe solar wall were simulated and analyzed for various types of air ducts. While determining regularities of specific heat transfer, three variants of holes were selected with the sizes of 30×30 mm, 50×50 mm, and 80×80 mm in square in order to determine temperature and velocity fields both at air intake and off-take.

Simulation was performed for the same climatic parameters and internal calculated temperature (18°C). The simulation results are illustrated in Fig. 2, Fig. 3, and Fig. 4.

Fig2: Temperature and velocity fields on air intake at 08:00 with hole size of 30×30 mm

Fig3: Temperature and velocity fields on air intake at 08:00 with hole size of 50×50 mm

Fig4: Temperature and velocity fields on air intake at 08:00 with hole size of 80×80 mm

On the basis of simulation results it was established that at 08:00 o'clock, January 22, the screen could not be heated at once due to low intensity of radiation. At that time the air temperature in interlayer is higher than that in air intake, that is, the air density in the interlayer is lower. However, at hole sizes of 30×30 mm the air flow is directed outside, hence, heat losses take place (see Fig. 2). With increase in hole sizes the air flow varies, when hole sizes increase to 50×50 mm, the air flow via air intake is
oriented inside, though, at interface of air intake there occurs vortex (see Fig. 3), preventing heat exchange and heating of main wall using porous screen. With increase in hole sizes to 80×80 mm, the vortex disappears and air flow steadily passes via air interlayer inside, the air temperature in the interlayer increases by 12°C (see Fig. 4).

4 Discussion

The same procedure was applied to the remaining stages of simulation at similar hole sizes at other times (13:00, 16:00, 23:00). It has been established that at any time the air flow is directed outside only at hole sizes of 30×30 mm. At hole sizes of 50×50 mm the inlet air velocity is higher, though, the velocity and inside flow rate decrease significantly in the interlayer due to vortex at inlet. Thus, the inward air is efficiently heated by screen and main wall. On the contrary, with hole sizes of 80×80 mm the inward air velocity is lower at intake but higher in the interlayer, hence, the inward flow is heated inefficiently. Heat losses and outward heat flow from southern solar wall as a function of various hole sizes of air intake and off-take are illustrated in Fig. 5 and Fig. 6.

Fig5: Comparison of heat losses through southern solar wall with various hole sizes

It can be seen in Fig. 5 and Fig. 6 that at any time on January 22 heat losses on southern solar wall occur at any hole sizes. With solar radiation heat release from screen decreases with decrease in hole sizes and main wall is not heated by porous screen. Without solar radiation (at night) heat release from screen is intensified, though, the screen hole sizes do not influence significantly on heat losses.

Fig6: Comparison of specific heat flow across southern solar wall with various hole sizes

5 Conclusion

1. It is established that the structure, sizes and thermal features of screen influence greatly on heat and air exchange of solar wall as exemplified by position and sizes of air intake and off-take.

2. On the basis of mathematical simulation, it is determined that at the air intake sizes on screen equaling to 30×30 mm or lower, the intentional heat and air exchange through solar wall does not take place at all times of the day in cold seasons.

3. It would be reasonable to expand the sizes of air intake and off-take thus promoting heat and air exchange through solar wall, since rooms are ventilated in cold seasons. However, increase in air flow would permit to decrease heating of fresh air through solar wall. Aiming at efficiency of air exchange, it is proposed to select the sizes of air intake in screen of 60–70 mm.

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References


