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THERMAL PERFORMANCE OF A HOUSE WITH VENTILATED WALL

Z. Zhuang[1*], J.Y. Ying[2]

1 Collage of Architecture and Urban Planning, Tongji University, Shanghai 200092, China (Corresponding Author)

2 Collage of Architecture and Urban Planning, Tongji University, Shanghai 200092, China

ABSTRACT

This paper proposes the use of a heavy ventilated wall to store natural energy and improve heating performance. An ideal numerical model was setup, and the thermal performance and annual heating contribution under different heating power, building insulation, airtightness and climates were explored by case studies. It is found that the ventilated wall with heat source has the potentials for creating a stable thermal environment, and also contributes to reducing building heating load. The initial findings can help engineers to develop design proposals for building envelops with an active heat source at the early design stage.

Keywords: thermal performance, ventilated wall, building energy consumption

NONMENCLATURE

Abbreviations	
ACH	air changes per hour
HLDR	heating load decreasing ratio
HL_s	auxiliary heating load excluding the contribution from heat source, W/m^2
HL_t	heating load index of the traditional building, W/m^2
$T_{i,base}$	base indoor air temperature without air-conditioning,℃
$T_{i,baseA}$	base indoor air temperature without air-conditioning for Case A,℃
$T_{i,set}$	the design indoor air temperature in winter,℃
SCTH	subcooling temperature hours of indoor air,℃
SCDR	subcooling temperature hours decreasing ratio

1. INTRODUCTION

Maintaining building's indoor thermal environment requires consuming energy. A primary measure to minimize the energy use is to enhance the thermal and energy performance of the building envelope through enforcing active and/or passive measures. Generally, building envelope is composed of thermal mass, which has certain thermal storage capacity related to its density, specific heat capacity and thermal conductivity. Both theoretical analysis and experimental results have shown that thermal mass is particularly important for sustainable design due to its capability to reduce building cooling and/or heating loads, balance the energy supply and demand at different times and also provide a more stable and comfortable thermal environment for occupants [1-4].

Therefore, this paper proposes an ideal numerical model for a building equipped with ventilated air layers utilizing natural energy was setup, and the heating performance under different influence factors and climatic conditions were studied. The results can help engineers to design building envelops within an active heat source at the early design stage.

2. METHODS

2.1 Basic considerations and model assumptions

An ideal single-zone building equipped with ventilated air layers with a heat source inside, as shown in Fig 1, was considered for the case study to explore their thermal performance and significant influence factors. The following assumptions were made to setup the dynamic thermal models for the buildings with ventilated air layers: 1) The air inside the ventilated layers is assumed to be fully mixed, i.e. its temperature

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distribution is uniform.2) The heat input in the ventilated air layers is set as the net heat gain.

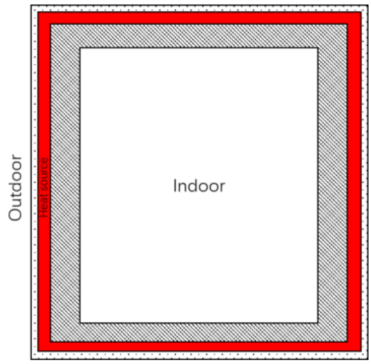


Fig 1 Principle of a ventilated wall with heat source

In order to analyze the thermal performance and its annual heating contribution under different influence factors and climatic conditions, the DeST (Designer's Simulation Toolkit), a simulation tool for building energy consumption and HVAC system developed by Tsinghua University during 1990s was used for modelling[5].

2.2 Case and scenario settings

To analyze thermal performance of the building with ventilated wall, three single-zone buildings (Building A, B and C) served as baseline cases are chosen for numerical calculations and comparisons. Building A is a traditional bedroom without indoor heat source, Building B is a traditional bedroom with surplus heat from a stove, and Building C is the bedroom with ventilated air layers having the same heat source. The parameter settings of all the scenarios are given in Table 1, which are almost the same except the heat source location. The TMY data provided hourly climate data, and Shanghai was chosen as the baseline location. Various simulations were performed to investigate the effects of heating pattern, building insulation and air change rate on indoor thermal environment and heating load. The house is heated three times a day, at 5:00 am., 11:00 am. and 17:00 pm., lasting for 60 minutes respectively and the base heat source power is set as 5kW. To evaluate the insulation effect, 50mm polystyrene panel insulation were added in the external walls and roof assemblies. The design indoor air temperature in winter is set to be 18°C.

Table 1 Component constructions and parameter settings

Item	Description
Size	3.0 m×3.0m×3.0m(L×W×H)
External wall	240mm clay brick and 10mm plaster layer at either side
Roof	10mm tile, 160mm clay and 80mm straw
Floor	20mm concrete and 100mm soil
South window	Single layer, 6 mm glass, size: 1.5m×1.5m
North door	Timber framing, size: 0.8m×2.7m
Occupancy and lighting	People: 2×64W/p, from 18:00 to 6:00. Lights: 60W, from 18:00 to 22:00. Airtightness: air changes per hour 1.0.
Heat source	Building A: without heat source Building B: indoor air with heat source Building C: ventilated wall with heat source

2.3 Performance evaluation index

The subcooling temperature hours of indoor air and subcooling temperature hours decreasing ratio based on Case A were defined to evaluate the indoor thermal level by the heat alone.

$$SCTH = \sum\left(T_{i,set} - T_{i,base}\right)^{+} \quad (1)$$

$$SCDR = \sum\left(T_{i,set} - T_{i,base}\right)^{+} / \sum\left(T_{i,set} - T_{i,base\ A}\right)^{+} \quad (2)$$

where + denotes that only the hour with the base temperature lower than the design air temperature is counted.

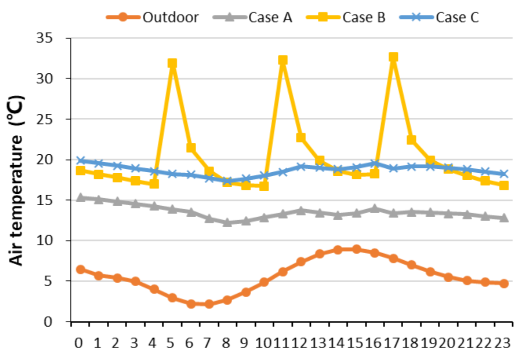
In addition, the heating load decreasing ratio is defined to describe the contribution of the embodied energy of ventilated wall to building heating load.

$$HLDR = (HL_t - HL_s)/HL_t \quad (3)$$

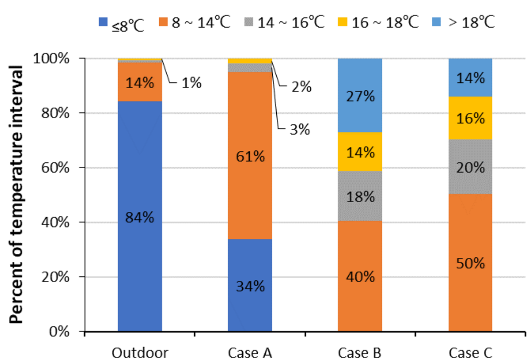
3. RESULTS AND DISCUSSION

3.1 Thermal response of ventilated wall

The simulated variations of the base indoor air temperature under three cases are shown in Fig 2(a) for one day in January in Shanghai. It can be seen that both air temperatures of Case B and C are about 5 °C higher than that of Case A due to the heat input. By comparing Case B with Case C, the indoor air temperature of Case B increases quickly during the heating time, and then falls as the heat source removed, which causes a big variation, about 32 °C during the heating period and 16 °C during the non-heating period. However, the results of Case C look favorable with less variation and the mean air temperature during the non-heating period is higher than that of Case B. Fig 2(b) illustrates the statistical distribution of indoor air temperature intervals for different cases in January. The Case A shows the current indoor thermal level without any heat source, and the indoor air temperature is lower than 18 °C during the whole month, and even lower than 8 °C in 34% of the duration. Therefore, the space heating is eagerly required. The average indoor air temperatures of Case B and Case C are improved by 7.0 °C and 5.2°C respectively against Case A. In addition, both indoor air temperatures are higher than 18 °C in 27% and 14% of the duration respectively, and the coldest is not less than 8 °C. This implied that the utilization of the surplus heat within walls can significantly improve the base indoor air temperature, which also helps to reduce the commercial energy consumption compared to a traditional air-conditioning system. Despite that the degree of heating capacity of Case C is slightly lower than that of Case B, the indoor air temperature variation of Case C is more moderate. In reality, buildings are often intermittently heated most of the time. So the heating pattern of Case C demonstrates the potentials for creating a stable thermal environment and utilizing surplus heat to achieve energy savings.



(a)

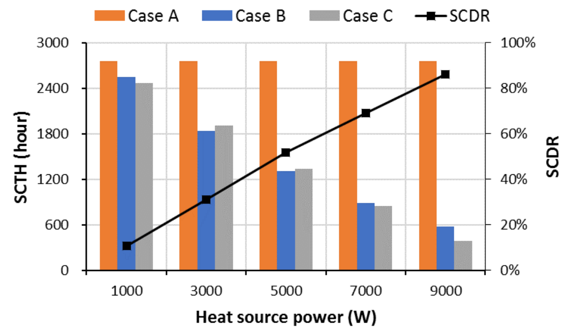


(b)

Fig 2 Variation/distribution of base indoor air temperature

3.2 Effect of heat power

Fig 3(a) illustrates the base indoor air temperature under different heat source powers. The larger the heat source power is, the greater the rise of indoor air temperature is. The subcooling temperature hours of Case B and C linearly go up as the heat power increases. The SCDR quickly increases from 5% to 88% as the heat power increases from 1kW to 9kW for Case C. Similarly, in Fig 3(b) the heating load indexes for Case B and C linearly decrease along with the increase of heat power, and the heating load for Case C is significantly lower than the other two cases. Meanwhile, the HLDR linearly increases from 19% to 58% as the heat power increases from 1kW to 9kW for Case C. Therefore, maximizing utilization of heat source within walls is an effective way to improve indoor thermal environment.



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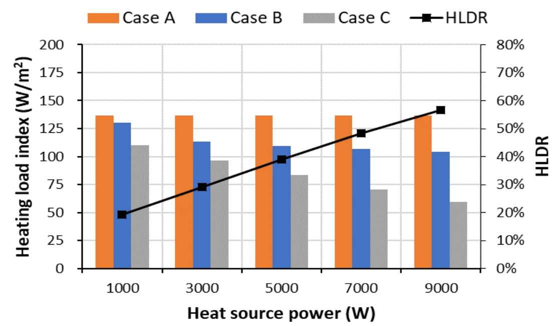
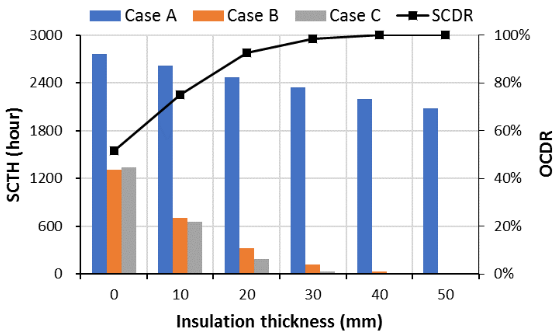


(b)

Fig 3 Distribution of base indoor air temperature under different heat powers

3.3 Effect of building insulation level

Fig 4(a) illustrates the base indoor air temperature under different insulation thicknesses. By adding the insulation layer of polyurethane foam board at the outside of external walls and roof, the indoor air temperatures of these three cases can be further improved, especially for Case B and C with the SCTH dropping to zero or near zero. The SCDR quickly increases from 50% to 100% as the insulation thickness increases from 0 to 40mm for Case C. This implies that the requirement of indoor thermal comfort environment can be only met by using the ventilated wall when the building insulation level is high enough. Fig 4(b) shows the results of heating load indexes under different insulation thicknesses. It can be seen that the heating load index becomes zero and the HLDR is equal to 100% as the thickness is larger than 40mm, and no extra air-conditioning system is required for home space heating. Hence, building insulation plays an important role in improving indoor air temperature, and an appropriate insulation design contributes to achieving indoor thermal comfort and low energy consumption without operating an air-conditioning system.



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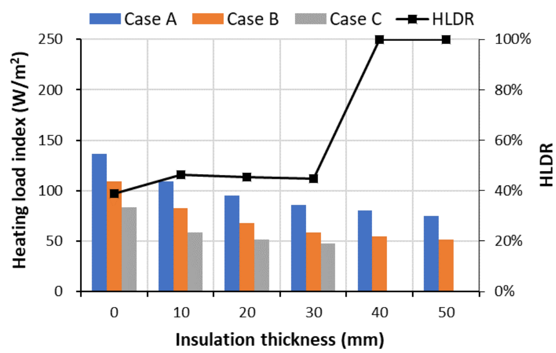
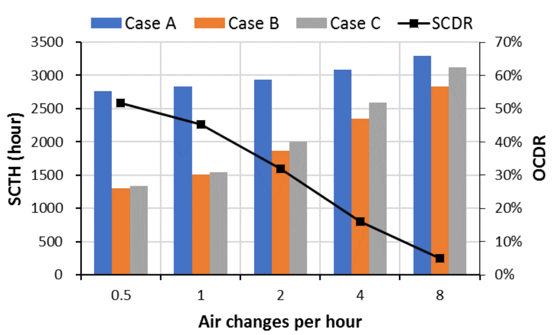


(b)

Fig 4 Base indoor air temperature and heating load index under different insulations

3.4 Effect of building airtightness



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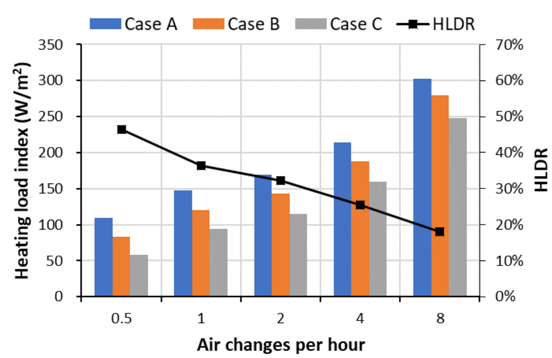

(b)

Fig 5 Base indoor air temperature and heating load index under different ACHs

Fig 5(a) illustrates the base indoor air temperature under different ACHs. The better the air tightness of the room, the greater the rise of indoor air temperature. The SCTH for Case A slightly increases as ACHs increase, while those for Case B and Case C linearly go up. The SCDR quickly increases from 5% to 51% as the ACH decreases from 8.0 to 0.5 for Case C. Similarly, the heating load indexes for Case A, B and C linearly increase along with the increase of ACHs, and the heating load for Case C is significantly lower than the other two cases. Meanwhile, the HLDR quickly increases from 18% to 48% as the ACH decreases from 8.0 to 0.5 for Case C, as shown in Fig 5(b). Therefore, the room air tightness is an important factor that influences indoor thermal environment.

4. CONCLUSIONS

The effects of heating pattern, building insulation levels and airtightness on the thermal performance of a building with ventilated wall were discussed. It is found that: the use of the ventilated wall with heat sources has the potentials for creating a stable thermal environment, and it also contributes to reducing building heating load. By adding insulation into the building envelop or improve the airtightness, the indoor air temperatures can be further improved. The experiment test and optimization study of EVA will be done in the next step.

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