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A new idea of building energy efficiency: The heat transfer coefficient changing with outdoor temperature wall

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Abstract. The building wall is the main interface of the interior and exterior of the building and is the main channel for the exchange of heat between the interior and exterior of the building. Therefore, reducing the wall energy consumption is one of the main methods to reduce the energy consumption of the building, in the traditional building. In the energy-saving design of the envelope structure, the wall heat transfer coefficient is considered as a fixed value. The constant wall heat transfer coefficient is not conducive to the timely use of outdoor air heat dissipation or heating in buildings in areas with relatively poor daily temperatures. In order to make better use of the outdoor air and to reduce the energy consumption of buildings. This research presents a new type of wall in view of the properties that traditional building structure material's heat transfer coefficient is relatively stable, which the heat transfer coefficient changing with outdoor temperature. The characteristic of the heat transfer coefficient changing with temperature outdoor wall is the use of the natural cold/heat energy to adjust its heat transfer coefficient, at the same time it reduces indoor heating/cooling energy consumption and saves energy. This paper studies the principle and performance about regulating the heat transfer coefficient of the heat transfer coefficient changing with outdoor temperature wall and verifies the energy saving effect and automatic adjustment characteristic of the heat transfer coefficient by experimental analysis and theoretical calculation of this wall.

1. Introduction

Building wall is the main interface of building internal and external environment, as well as the main channel for heat exchange of building internal and external environment, thereby reducing the energy consumption of building wall is one of the main method to reduce the building energy consumption, the heat transfer coefficient of wall is considered as a fixed value in traditional design of building structure energy efficiency. In cold region, the main method of reducing the heat transfer of wall is to reduce the heat transfer coefficient, while in hot region, the heat transfer of wall is usually increased in the way that increasing the heat transfer coefficient of wall. But many areas (such as Xinjiang, Inner Mongolia, Gansu, Ningxia, etc.) are a continental climate in China, where the temperature daily range are very large and the outdoor temperature are usually in a large range of fluctuation, for example, in summer, these areas are often appear the phenomenon that outdoor temperature is higher than indoor air temperature during daytime, while in night, the outdoor temperature is lower than indoor air temperature. So in these areas, if the design value of wall heat transfer coefficient is too small, it will hinder the building's heat dissipation from using natural outdoor cold source (low temperature of outdoor air, the sky radiation, etc.) at night. The heat gain will increase during the day if the wall heat transfer coefficient is too large. The heat transfer coefficient changing with outdoor temperature wall (hereinafter referred to as the heat transfer coefficient changing wall) can be a good solution to this problem. In summer, for instance, when the outdoor temperature is higher than the indoor temperature, the heat transfer coefficient of this wall automatically become smaller to reduce the outdoor environment and indoor heat transfer through the wall, While the outdoor temperature is lower than the indoor temperature, the heat transfer coefficient of this wall automatically become larger to increase the outdoor environment and indoor heat transfer through the wall. The heat transfer coefficient changing wall can automatically adapt to the characteristics of the outdoor changing temperature and reduce the energy consumption of building structure.

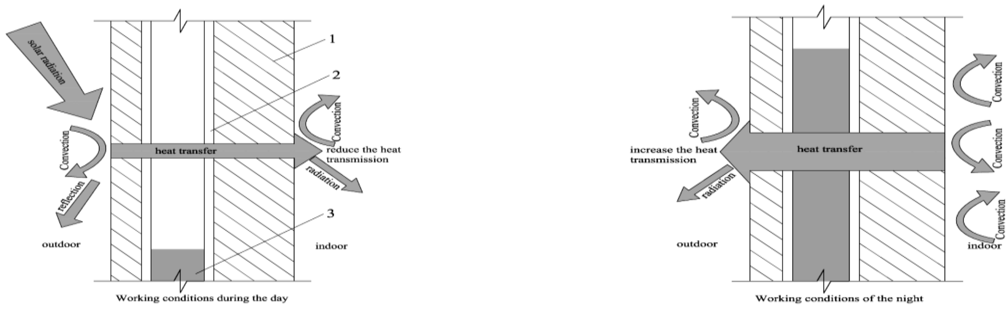
The main characteristic of this heat transfer coefficient changing wall is the automatic adjusting heat transfer coefficient according to the change of outdoor temperature that increases "good" heat transfer and reduces "bad" heat transfer. The essence of the heat transfer coefficient changing wall energy saving is the use of natural outdoor cold/heat source (mainly the energy contained in outdoor air). The existing similar energy saving way to this topic idea mainly is the natural ventilation, this approach is focused on the direct heat exchange of indoor and outdoor air to achieve the purpose of energy saving.

Natural ventilation is a widely used way of saving energy, the vital way to realize the heat exchange between indoor and outdoor is air mass exchange. Research on natural ventilation mainly focuses on its principles [1,2], influencing factors [3,4], and improvement measures [5-7]. The natural ventilation has higher demand to the outside conditions in the practical application. In recent years, with the construction of industrialization and urbanization in our country, the air are more or less polluted in most areas , there is a lot of dust and particulate matters in urban outdoor air which greatly hindered the application of natural ventilation. Especially in some big cities and provincial capital cities, due to the large population density and the prominent contradiction between human and land, it makes the priority of increasing the land utilization in the architectural design instead of the application of natural ventilation in building structure design.

Natural ventilation is the typical technology to use the natural outdoor cold/heat source, but there are still some intrinsic shortcomings of these technologies which limit the application of them. The heat transfer coefficient changing wall this paper mentioned could be a good solution to above problems, it can adjust the heat transfer process of building internal and external environment without the indoor and outdoor air direct contacting and prevent the pollution of indoor air. The heat transfer coefficient changing wall can make full use of the characteristics that these areas' big temperature differences between day and night and also as much as possible use the natural outdoor cold/heat source.

2. The realization form and working principle

2.1. The realization form



(a) (b)

Figure 1. Working principle diagram of the heat transfer coefficient changing wall in Summer. (a) The daytime working principle diagram and (b) The night working principle diagram.
Notes: 1—masonry structure, 2—the waterproof layer, 3—water.

Figures 1(a) and 1(b) are the proposed working principle diagram of the heat transfer coefficient changing wall in this paper, the main characteristic of this wall is the adding of a water filled layer in the wall structure (heat transfer coefficient adjusting layer), when the environment temperature changes, we can adjust the heat transfer coefficient of the wall by controlling the water filling height of the water filled layer. For practical use, the water used in the wall can be stored in a water tank, used repeatedly or used for irrigation and domestic water.

2.2. The working principle

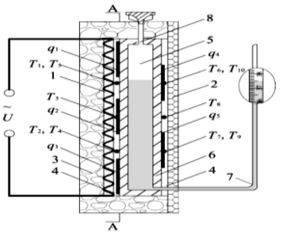
Figure 1(a) is the daytime working principle diagram of the heat transfer coefficient changing wall in Summer, when the environment temperature is higher than indoor temperature, reducing the water filling height of the layer to keep the water filling height in a lower level to adjust the heat transfer coefficient of the heat transfer coefficient adjusting layer, at this point, air is the main medium of heat conduction of the heat transfer coefficient adjusting layer, the heat transfer coefficient of the wall is relative smaller since the smaller thermal conductivity of air, it can reduce the rate of heat transfer external environment to indoor. Figure 1(b) is the night working principle diagram of the heat transfer coefficient changing wall in Summer, when the environment temperature is lower than indoor temperature, increasing the water filling height of the layer to keep the water filling height in a higher level to adjust the heat transfer coefficient of the heat transfer coefficient adjusting layer, at this point, water is the main medium of heat conduction of the heat transfer coefficient adjusting layer, the heat transfer coefficient of the wall is relative larger since the larger thermal conductivity of water, it can increase the rate of heat transfer indoor to external environment.

When the environment temperature is higher than indoor temperature in Winter daytime, increasing the water filling height of the layer to keep the water filling height in a higher level to adjust the heat transfer coefficient of the heat transfer coefficient adjusting layer, at this point, water is the main medium of heat conduction of the heat transfer coefficient adjusting layer, the heat transfer coefficient of the wall is relative larger since the larger thermal conductivity of water, it can increase the rate of heat transfer external environment to indoor. When the environment temperature is lower than indoor temperature, reducing the water filling height of the layer to keep the water filling height in a lower level to adjust the heat transfer coefficient of the heat transfer coefficient adjusting layer, at this point, air is the main medium of heat conduction of the heat transfer coefficient adjusting layer, the heat transfer coefficient of the wall is relative smaller since the smaller thermal conductivity of air, it can reduce the rate of heat transfer indoor to external environment, to some extent, the heat transfer coefficient adjusting layer reduces the heating/cooling energy consumption of indoor air conditioning equipment and save by using of natural outdoor cold/heat source.

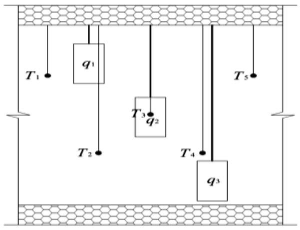
3. The experimental setup and the analysis of the data processing

3.1. The experimental setup

3.1.1. The experimental device. In order to test the heat transfer coefficient of the heat transfer coefficient adjusting layer, this research set up a test bench as it shown in figure 2(a), this test bench mainly includes the insulation layer, the heating layer, the left test layer, the heat transfer coefficient adjusting layers, the right test layer, and the stable layer. In order to heat the experimental device, the resistance heating wire is arranged uniformly on the heating layer. The heat transfer coefficient adjusting layer is composed of a stainless steel cavity which could store a certain amount of water. There are five temperature measuring points (T1~T5) and three heat flux density measuring points (q1~q3) on the left test layer, the decorate position as shown in figure 2(b). The right test layer layout of five temperature measuring points (T6~T10) and two heat flux density measuring points (q4~q5). The stable layer is used to balance the heat release and extend the cooling time within a certain time of the heat transfer coefficient adjusting layer.



(a)



(b)

Figure 2. The experimental device. (a) The heat transfer coefficient adjusting layer test device and (b) Arrangement of measuring points of section A – A.

Notes: 1—heating layer, 2—stable layer, 3—insulation layer, 4—test layer, 5—heat transfer coefficient adjusting layer, 6— stainless steel liquid cavity, 7—connecting pipe, 8— the inlet opening, 9—drain valve ,T_1 ~ T_{10}—temperature measuring point, q_1 ~ q_5—heat flux density measuring points.

3.1.2. The experimental scheme. The experiment respectively tests heat transfer coefficient of the heat transfer coefficient adjusting layer when temperature is in a stable state, the selected standard of temperature stable state in this study is: if the temperature and heat flux density of heat transfer coefficient adjusting layer were basically remain unchanged within 1h as heating after a period of time, it is considered that the test have reached a stable state. This study testes the heat flux density of the heat transfer coefficient adjusting layer by changing the height of the water filling percentage of cavity's total height from 0% (for all air heat transfer state)to 25%, 50%, 75% and 100% (for all water heat transfer state) in the stable temperature conditions of 30℃, 40℃ and 50℃ at the same time. The experiment uses the connecting pipe to measuring water filling height of the experimental device and uses the transformer to adjusting the heating power controlling the stable temperature of the heat transfer coefficient adjusting layer. Temperature test instrument is thermocouple, the thermocouple data is collected by Agilent 34970 A, the heat flux density test instrument is a multiple channel temperature heat flux sensor JTNT - A/C.

3.2. The experimental data analysis

Figure 3 is the equivalent heat conductivity coefficient of the heat transfer coefficient adjusting layer under different water filling height with stable temperature respective at 30℃, 40℃and 50℃, figure 4 is the change multiple of equivalent heat conductivity coefficient of the heat transfer coefficient adjusting layer under different water filling height with stable temperature respective at 30℃, 40℃ and 50℃. The figure 4 shows that the equivalent heat conductivity coefficient of the heat transfer coefficient adjusting layer is highly increased with the rising of water filling height in the cavity at a certain stable temperature, also when the water filling height in the cavity at a certain value, the equivalent heat conductivity coefficient of the heat transfer coefficient adjusting layer is highly increased with the rising stable temperature.

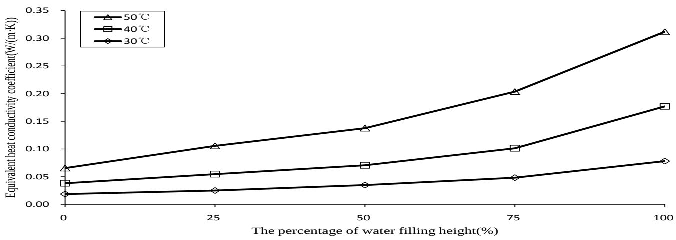


Figure 3. The equivalent heat conductivity coefficient of the heat transfer coefficient adjusting layer under different water filling height with stable temperature respective at 30℃, 40℃ and 50℃.

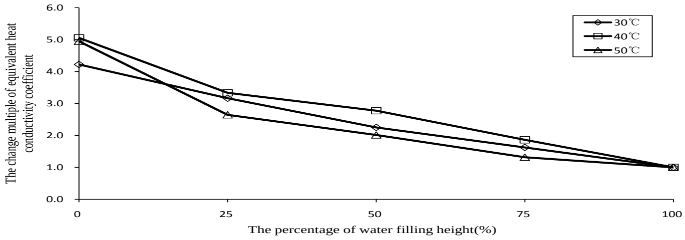


Figure 4. The change multiple of equivalent heat conductivity coefficient of the heat transfer coefficient adjusting layer under different water filling height with stable temperature respective at 30℃, 40℃ and 50℃.

4. The establishment of calculation model and calculation

4.1. The establishment of calculation model and calculation

By analysis the above experiment and experimental data, we learn that the equivalent heat conductivity coefficient of the heat transfer coefficient adjusting layer are related to heat transfer temperature difference and water filling height.

Because of limitation of the fluid motion when the natural convection occurs in the cavity [8], we simplify the heat transfer coefficient adjusting layer into a vertical hollow cavity as shown in figure 5, it is assumed that the heat transfer of this cavity only along the direction of the cavity's thickness. Figure 5 shows Four possible heat transfer state when the thickness of the cavity changes, here, $\delta 1 < \delta 2 < \delta 3 < \delta 4$. In order to get reliable calculation results, we assume that the heat surface temperature of cavity for Tw1=50℃, the cold surface temperature for Tw2=30℃, the length of the cavity for L=0.6 m, and the height of the cavity for H=0.5 m, calculating the heat transfer coefficient of the cavity use the following limited space corresponding for natural convection heat transfer calculation when the thickness changes: (1) Calculating the Grash of number Grδ: (2) Calculating the Nusselt number Nu: (3) Calculating the natural convection heat transfer coefficient h of the cavity.

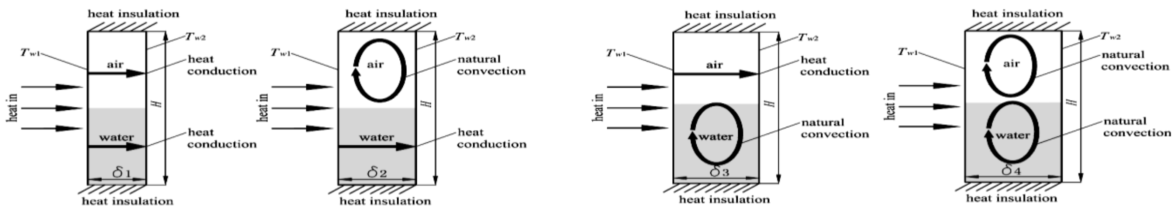


Figure 5. Four possible heat transfer state under different cavity thickness. (a) For heat conduction of air and water, (b) For natural convection of air, heat conduction of water, (c) For heat conduction of air, natural convection of water and (d) For natural convection of air and water.

4.2. Analysis of data

Figure 6 shows the natural convection heat transfer coefficient of air at different chamber thicknesses. Figure 7 shows the natural convection heat transfer coefficient of water at different chamber thicknesses. In figures 6 and 7, the chamber thickness δ is less than the thickness at point P (δ< For 0.018 m), the heat transfer mode of air and water is heat conduction or transitional state. When the thickness δ of the chamber is greater than or equal to the thickness at point P (δ≥0.018 m), the heat transfer mode of air and water is in natural convection state. It can be seen from figure 6 that the natural convection heat transfer coefficient of air gradually decreases with the increase of the cavity thickness δ, and finally stabilizes. It can be seen from figure 7 that the natural convection heat transfer coefficient of water gradually increases with the increase of the cavity thickness δ, and finally tends to be stable. In figure 8, the equivalent heat transfer coefficient K of the cavity under different water filling heights. It can be seen from figure 8 that when the cavity thickness δ is constant, the equivalent heat transfer coefficient K of the cavity increases with the increase of the filling water height of the cavity. When the cavity is filled with water at a certain height, the equivalent heat transfer coefficient K of the cavity increases with the increase of the cavity thickness δ. Figure 9 shows the relationship between the equivalent thermal conductivity of the cavity and the thickness δ of the cavity when the filling height of the cavity accounts for 0%, 25%, 50%, 75%, and 100% of the total height of the cavity. As can be seen from the figure, when the water filling height is constant, the equivalent thermal conductivity of the cavity increases with the thickness of the cavity. When the thickness of the cavity is constant, the equivalent thermal conductivity of the cavity increases as the height of the water in the cavity increases.

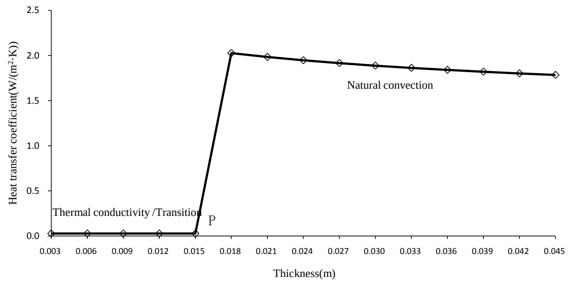


Figure 6. The natural convection heat transfer coefficient of air under different thickness of cavity.

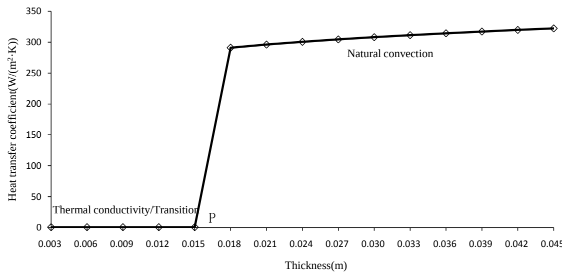


Figure 7. The natural convection heat transfer coefficient of water under different thickness of cavity.

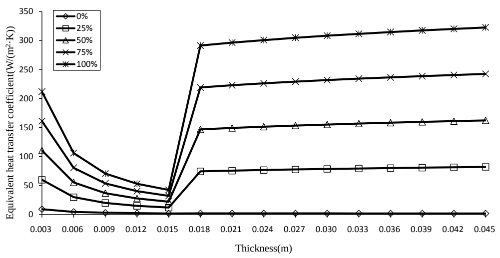


Figure 8. The equivalent heat transfer coefficient of the cavity under different water filling height.

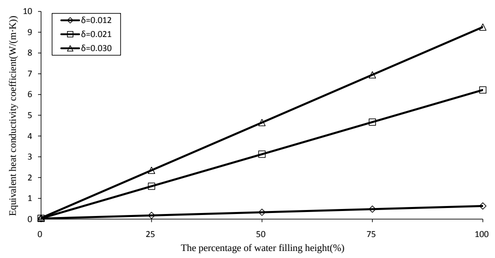


Figure 9. The equivalent heat conductivity coefficient of the cavity under different water filling height.

5. Conclusion

This paper proposed a new idea on building energy saving. The device proposed in this paper also has many limitations and difficulties. For example, difficult to construct, the device takes up a lot of space, the economic cost is high, and the adjustment is difficult. This topic aims to propose the variable heat transfer coefficient wall. The experimental results show that when the stable temperature is fixed, the equivalent thermal conductivity of the heat transfer coefficient adjusting layer increases with the increase of water filling height; when the water filling height is constant, the equivalent thermal conductivity of the heat transfer coefficient adjusting layer rises with stable temperature. At the same time, the relationship between the thermal resistance R of the cavity and the thickness δ of the cavity and the water filling height was verified through theoretical analysis and calculation. The wall can adjust its own heat transfer coefficient by using the cold/heat energy contained in the environment, and to a certain extent, it can realize the automatic adjustment and control of the heat transfer coefficient.

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References

[1] Sacht H and Lukiantchuki M A 2017 Windows size and the performance of natural ventilation *Procedia Engineering* **196** 972-9

[2] Chen Y J, Norford L K, Samuelson H W and Malkawi A 2018 Optimal control of HVAC and window systems for natural ventilation through reinforcement learning *Energy Build.* **169** 195-205

[3] Homod R Z 2014 Energy saving by integrated control of natural ventilation and HVAC systems using model guide for comparison *Renew. Energy.* **79** 639-50

[4] Chen X M 2016 Energy saving potential of a ventilation system with a latent heatthermal energy storage unit under different climatic conditions *Energy Build.* **118** 339-49

[5] Cardinal N, Micucci M and Ruggiero F 2003 Analysis of energy saving using natural ventilation in a traditional Italian building *Energy Build.* **35** 153-9

[6] Chen S L, Lu J and Li Y C 2011 The experiment of solar phase change energy storage ventilation system *The Civil Construction and Environmental Engineering* **33** 97-100

[7] Bai Y F, Xu L and Liao X Y 2014 The research of affecting factors the phase change materials and natural ventilation at night to the tent indoor thermal environment *Refrigeration and Air Conditioning* **28** 556-9

[8] Yang S M and Tao W Q 2006 *Heat Transfer* (Higher Education Press, Beijing, China) **6** 155-72