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# A new type of passive solar energy utilization technology—The wall implanted with heat pipes

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ABSTRACT

The heat transfer performance on the wall has a great influence on the energy conservation and the indoor thermal comfort. Once it can be adjustable according to the requirement, the wall can effectively regulate the indoor temperature, thereby directly reducing the building energy consumption. In this paper, a new type of passive solar energy utilization technology, the wall implanted with heat pipes (WIHP), was proposed, and its heat transfer performance and energy-saving characteristic were investigated theoretically and experimentally with the typical meteorological data of Jinan. The results indicate that the theoretical results agree well with experimental ones. The heat transfer performance of the WIHP is adjustable and controllable, which can reduce the heating load and improve thermal environment. During the winter in a typical year, the heat loss of the south external wall is reduced by 14.47%. Therefore, such a type of wall can apparently improve the indoor thermal environment, which can be popularized in engineering applications.

## 1. Introduction

Wall, one of the most basic forms of a building, is the key component for energy saving in building enclosure structure [1–6]. Conventionally, once the wall is established, its thermal resistance can be basically regarded as a constant, which is not necessarily conducive to the energy conservation [7,8]. In winter, the outside surface temperature of the external wall (solar-air temperature) is higher than that of the ambient, and it is evidently higher than the inside surface temperature of the wall as a result of the solar radiation. If the thermal resistance of the wall is higher, the heat can‘t be transferred into the building by the wall effectively [9]. On the contrary, if the thermal resistance of the wall becomes lower, the heat transfer will raise the inside surface temperature of the wall to reduce the heating load, thereby improving the thermal environment. The afore-mentioned thermal process also can effectively improve the indoor thermal environment for the stage before or after the heating period. Similarly, once the temperature of the outside surface of external wall is lower than that of the inside surface during the night in summer, a lower thermal resistance will be helpful to the heat dissipation, thus reducing the air conditioning load and improving the thermal comfort.

Numerous studies have been focused on the thermal storage wall in order to enhance the heat absorption of the wall from solar energy in winter. Zhou [10], Esakkimuthu [11] and Zalewski et al. [12] studied the thermal storage wall using phase-change material experimentally, respectively. Halawa [13,14], Khalifa [15] and Shen et al. [16] simulated and analyzed the heat transfer characteristics of the thermal storage wall. Wang et al. [17] studied a passive solar house with water thermal storage wall. Cabeza et al. [18] tested the thermal properties and energy saving performance of a new innovative concrete with PCM. Chel et al. [19] estimated the passive heating potential of Trombe wall for a honey storage building by TRNSYS building simulation software. The thermal storage wall can enhance the availability of the solar energy, but the outside surface temperature of the external wall rises slowly in winter with a long lag time. Moreover, the indoor environment is prone to be overheating during the daytime in summer, as a result that the surface temperature of the thermal storage wall is too high [20].

Heat pipe is one of the most efficient heat transfer elements, and it can transfer a large number of heat without additional power consumption when the temperature difference is small [21]. Therefore, heat pipes have been widely used in heat recovery [22–24] as well as space heating. Zhang et al. [25] found that the thermal performance of the thermosyphon-embedded floor has much better heat performance than the common plastic embedded radiant floor. Zhao et al. [26] did experiments to prove that the solar-thermosyphon embedded radiant floor could improve the economy of solar heating system. Bian [27] studied a heating terminal device,

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**Nomenclature**

| | |
|---|---|
| $a$ | solar radiation absorptivity |
| $A$ | area ($m^2$) |
| $Ac$ | cross-sectional area ($m^2$) |
| $C_p$ | specific heat [kJ/(kg °C] |
| $d$ | diameter (m) |
| $g$ | gravitational acceleration ($m/s^2$) |
| $h$ | convective heat transfer coefficient[W/($m^2$ °C)] |
| $h_{fg}$ | latent heat of vaporization (kJ/kg) |
| $I$ | global solar irradiance (W/$m^2$) |
| $K$ | coefficient of heat transfer [W/($m^2$ °C) |
| $L$ | length (m) |
| $q$ | heat flux (W/$m^2$) |
| $R$ | thermal-conduction resistance (m °C/W) |
| $Rc$ | thermal resistance ($m^2$ °C/W) |
| $T$ | temperature (°C) |

*Greek symbols*

| | |
|---|---|
| $\rho$ | density (kg/$m^3$) |
| $\lambda$ | thermal conductivity [W/(m °C)] |
| $\alpha$ | heat exchange coefficient [W/($m^2$ °C)] |
| $\mu$ | dynamic viscosity (Pa s) |

*Subscript*

| | |
|---|---|
| *a* | air |
| *ah* | all of the heat pipe |
| *av* | average |
| *c* | condensing section |
| *e* | evaporating section |
| *em* | experimental |
| *eq* | equivalent |
| *ex* | exterior surface of condensing section |
| *h* | heat pipe |
| *i* | inside |
| *in* | inside surface of wall |
| *ip* | inside surface of the plaster |
| *l* | liquid |
| *o* | outside |
| *os* | outside surface of wall |
| *sat* | saturation |
| *v* | vapor |
| *sa* | solar-air |

combined heat pipe with wall, which can take advantages of low-temperature heat source and will not occupy indoor space. In order to make the advantages of heat pipes for the utilization of solar energy absorbed by the wall, the combination of gravity heat pipes with the wall, i.e. the wall implanted with heat pipes (WIHP), was put forward. As a result of the efficient heat transfer characteristic, one-way thermal conductivity and thermal switch of heat pipes [28–31] can lead to transfer heat into the buildings in winter and out of the buildings in summer. The heat transfer and energy-saving characteristics of the WIHP were investigated theoretically and experimentally.

## 2. Working principle

At present, the conventional building wall structure in the northern part of China is 200–250 mm thick concrete walls or lightweight masonry wall, with 20 mm cement mortar layer at the inner surface and dozens of millimeters thick insulation board at the outer surface. The microgravity heat pipes in millimeter level [32] are implanted in the crack of plastering mortar which is outside of the insulation board, and the condensing section (or evaporating section) are implanted in the cement mortar of the inner surface. Compared with the thickness of the insulation board and wall, the diameter of the micro heat pipes is much smaller. It can be regarded that the gravity heat pipes are well coupled with the wall structure of the wall and does much less harm to the performance of the wall in terms of strength. For the different types of walls, the changing of insulation material, between the condensing section and evaporating section, will not influence the operation of the heat pipes.

The WIHP combined heat pipes and automatic control with the wall thermal insulation technology forms a new passive composite wall with phase-change, heat storage, and heat release. Due to the efficiently unidirectional heat transfer characteristics of gravity heat pipes, the temperature difference between the outside and inside surfaces of the WIHP drives the heat transfer from outdoor to indoor in winter, whereas it is from indoor to outdoor when the outside surface temperature is lower than the inside surface temperature in summer. The heat switch characteristic of gravity heat pipes can prevent the wall from losing a large amount of heat in winter, whereas it tends to absorb too much heat in summer, which will lead to a higher indoor temperature. Therefore, the WIHP cleverly solves the contradiction between the outer envelope insulation and the utilization of the natural sources to maintain a more comfortable indoor thermal environment.

Fig. 1 illustrates the working principle of the WIHP. An intelligent control valve is equipped on the adiabatic section to realize the intelligent control of the WIHP by the induction of indoor thermal environment. In winter, the control valve on the south wall is open, while the valve on the north wall is closed. The south external wall increases the outside surface temperature gradually by absorbing solar energy, and maintains high outside surface temperature in a certain cumulative time. When the temperature of the outside surface is higher than that of the inside surface temperature, the working medium of the evaporating section in the lateral wall absorb heat to vaporize and then the steam at the condensing section in the wall lining is condensed to release heat to indoor. These improvements increase the inside surface temperature of the external wall in winter so as to improve the indoor thermal environment. In summer, the control valve on the north wall is open while the valve on the south wall is closed. Due to the north wall absorbing less heat radiation, the outside surface temperature of the north wall is low, especially at night. When the outside surface temperature of the external wall is lower than that of the inside surface, the working medium of the evaporating section in the wall lining absorbs heat to vaporize, and then the steam at the condensing section of the lateral wall is condensed to release heat to outdoor. These improvements reduce the inside surface temperature of the external wall, thereby improving the indoor thermal environment.

## 3. Theoretical analysis

The heat transfer progress of the WIHP is very complex, because it includes the heat transfer of heat pipes, the heat transfer and heat storage of the wall, et al. In order to investigate the progress theoretically, the following assumptions are applied:

(1) The heat transfer progress of wall and heat pipes is stable.
(2) The Reynolds number of the steam in the heat pipes is less than the local speed of sound.
(3) The temperature variation caused by the change of working medium viscosity in heat pipes is ignored,