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Research Paper

Heat pipe structure on heat transfer and energy saving performance of the wall implanted with heat pipes during the heating season

Ronghua Tan *, Zhigang Zhang

School of Energy and Safety Engineering, Tianjin Chengjian University, Tianjin 300384, China

HIGHLIGHTS

- The heat pipe structure of the WIHP was optimized.
- The RESL was optimized by the working-hours-weighted mean temperature.
- The heat pipes with a large diameter are preferable.
- The WIHP is energy-saving even with less working hours.

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ABSTRACT

The heat transfer coefficient of the wall implanted with heat pipes (WIHP) is closely related to its energy saving potential. In this paper, the influence factors of heat pipe structure on heat transfer coefficient were analyzed to enhance the heat transfer performance of the WIHP, such as the working temperature, the ratio of the evaporating section length (RESL) and the diameter of the heat pipe. The results show that the average equivalent heat transfer coefficient (EHTC) of the WIHP reaches the maximum of 1.24 W/(m^2 °C) at a RESL of 75%, and the RESL should be optimized based on the working-hours-weighted mean temperature. There is an approximately linear relationship between the average EHTC and the diameter of heat pipe. The energy saving potential of a typical building with the WIHP in Tianjin, China was analyzed, which shows that the WIHP has a great energy saving potential during the heating season.

1. Introduction

The acceleration of urbanization and the rise in the demand of the indoor comfort have been increasing the energy consumption in buildings, especially in developing countries [1,2]. Face the challenges, the development of renewable energy utilization technology provides a breakthrough to replace conventional energy in buildings. Compared with other renewable energies, solar energy is less subject to the geographical condition and usage environment, thus the utilization of solar energy in buildings is widely promoted [3,4]. In northern China, the solar energy resource is very abundant, and the average annual direct radiation is basically more than 1300 kW h/m^2, except for the three northeastern provinces. Hence, it is particularly promising to make full use of the solar energy to provide comfortable environments and reduce the energy consumption of the buildings in these areas.

Different solar utilization technologies have been studied to improve the energy utilization efficiency in buildings. Zhu and Chen [5] presented an improved passive solar house suitable for cold area of China. Chen and Liu [6] studied passive solar composite wall by numerical analysis. Li et al. [7], Ozgener and Hepbasli [8] and Sözen et al. [9] studied the solar energy assisted heat pump systems. The latent heat storage is also applied in solar heat pump heating system to ensure that the system can provide the maximum energy efficiency [10,11]. Zhao et al. [12] and Martínez et al. [13] researched a floor heating system based on solar radiant, and the results also show that system could improve the economy of solar heating system and have good heat transfer performance. The utilization of solar energy does a good job in the heat pump system and the latent heat storage system.

As an important part of buildings, wall, plays a key role in the stability of the indoor thermal comfort and the energy saving of buildings [14–20]. Currently, the difficulty of the solar energy utilization on wall is that the solar energy is hard to be transferred into indoor, because of the high thermal resistance of the traditional wall [21–24]. The thermal storage walls are extensively

* Corresponding author. Tel.: +86 15202250025.
E-mail address: tanronghua510613@163.com (R. Tan).

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Nomenclature

a	solar radiation absorptivity
A	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)
T	temperature (°C)

Greek symbols

ρ	density (kg/m^3)
λ	thermal conductivity (W/(m °C))
α	heat exchange coefficient (W/(m^2 °C))
μ	dynamic viscosity (Pa s)

Subscript

a	air
ad	adiabatic section
av	average
c	condensing section
e	evaporating section
eq	equivalent
ex	exterior surface of condensing section
h	heat pipe
i	inside
ip	inside surface of the plaster
l	liquid
o	outside
sat	saturation
v	vapor

Abbreviations

WIHP	wall implanted with heat pipes
EHTC	average equivalent heat transfer coefficient
RESL	ratio of the evaporating section length

studied to enhance the availability of the solar energy on wall, such as the Trombe walls [25] and the wall with phase change material [26,27]. However, the outside surface temperature of the external wall rises slowly in winter, and the overheating is ever-present during the daytime that results from the high surface temperature of the thermal storage wall in summer [28], which go against the utilization of the solar energy.

Heat pipe is an efficient heat transport device, and it can transfer a large number of heat even with the small temperature difference [29]. Therefore, heat pipes have been widely used in space heating as well as heat recovery [30–32]. Taking the advantage of the heat transfer characteristics of heat pipes, Zhang et al. [33] implanted heat pipes into the wall to construct a new solar energy utilization technology—the wall implanted with heat pipes (WIHP), which can transfer the solar energy projected on the wall surface into the indoor environment quickly. The applicability of the WIHP during the heating season was studied by Sun et al. [34], and the result indicated that the WIHP in northern China had a lot of working hours and high energy saving rate during the heating season, which can be applied in most of the central heating area. The previous literatures mainly focus on the technical introduction and the applicability of the WIHP in a macroscopic view. Compared with the conventional wall, the working process of the WIHP is more complicated. Therefore, the working process of the WIHP should be further studied in order to promote the application of the WIHP.

This study focuses on the structure of the heat pipes of the WIHP to improve the energy saving performance in buildings. The structure of the heat pipes was analyzed to optimize the heat transfer performance of WIHP theoretically. The energy saving performance of the building with WIHP is also studied.

2. Description of the WIHP

The conventional building wall in northern China is presently 200–250 mm thick concrete walls with dozens of millimeters insulation board at the outside surface and 20 mm cement mortar layer at the outside and inside surface. The millimeter-scale micro gravity heat pipes are implanted in the cement mortar layer which is outside of the insulation board, and the condensing section (or evaporating section during the cooling season) is implanted in the cement mortar layer of the inside surface. The WIHP is the combination of the wall structure and the millimeter-scale micro gravity heat pipes [35]. Compared with the thickness of the wall and the insulation board, the millimeter-scale micro heat pipes are much smaller. Thus, the gravity heat pipes do much less harm to the performance of the wall and are well coupled with the wall structure. The WIHP is a new type of passive solar technology based on heat pipes, and the structure and working principle are shown in Fig. 1. Intelligent control valves are equipped on the adiabatic section to realize the switch control of the south and north WIHPs. During the heating season, the control valve of the south wall is open, while the valve of the north wall is closed. Thus, the south WIHP is in working condition, and the north WIHP is not working which is equivalent to conventional wall. During the cooling season, the control valve of the north wall is open, while the valve of the south wall is closed. Once the outside surface temperature of the south wall is higher than the inside surface temperature, the heat pipes will transfer the heat from the external environment to the indoor environment. When the outside surface temperature of the south wall is lower than the inside surface temperature, the heat pipes would stop working, due to the unidirectional heat transfer characteristics of heat pipes. The WIHP has the following characteristics:

(1) Controllable capability of the heat transfer

Heat pipe is an efficient heat transfer element, which has a small thermal resistance, thus it can transfer a large amount of heat, even in the case of small temperature difference. The temperature difference between the inside and outside surfaces of the wall can drive the WIHP transfer the solar energy projected on the surface of the external wall to the indoor environment. Because of the unidirectional heat transfer characteristics of the gravity heat pipe, the heat transfer process is irreversible. Thus the WIHP transfers heat from outdoor to indoor in a single direction, which can prevent the heat dissipation during the heating season when outside surface temperature of the southern exterior wall is lower than the inside surface temperature. The intelligent control valves can prevent the heat transfer process of the south external wall