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Active heat storage characteristics of active–passive triple wall with phase change material

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Abstract

In passive solar greenhouses, the solar energy obtained by the wall cannot be used efficiently for heating the indoor environment, due to a thermal-stable layer inside the wall, which is caused by the limitation in heat transfer properties of building materials. In order to solve this problem, a new system combining an active–passive triple phase change material wall (APTPCMW) and solar concentrators is proposed and introduced in this paper. To investigate the active heat storage performance of APTPCMW, an experiment is designed and carried out. From the experiment, the significant contribution of the new proposed system to improving the heat storage capacity of the middle layer of APTPCMW has been confirmed. Additionally, factors, namely, the gap between air tunnels, the flow direction of heated air, the temperature and velocity of the supply air, have been identified to have influence on the active heat storage performance of APTPCMW. For real applications, optimum operational conditions of APTPCMW have also been identified from the experiment.

Keywords: Active–passive triple PCM wall; Active heat storage; Heat transfer; Solar concentrator

1. Introduction

Due to the high speed increase of global population in current society, promoting the productivity in food by means of modern technologies is highly required (Sethi and Dubey, 2011). In order to provide suitable micro-climate for off-season crops, solar greenhouses are popularly used by both entrepreneurs and farmers (Sethi, 2009). Generally, the micro-climate of solar greenhouses can be influenced by several factors, such as outdoor meteorological conditions, soil thermal characteristics and thermal performance of solar greenhouse envelope. In the northern hemisphere, the north wall thermal performance in the solar greenhouse is particularly important (Din et al., 2003). Increasing its heat storage capacity can raise the air temperature in the solar greenhouse up to 10 °C and can cover 35–82% heating load of solar greenhouses (Sethi and Sharma, 2008).

A proper solution for increasing the north wall heat storage capacity is to incorporate phase change material (PCM) into the standard wall (Berroug et al., 2011; Beyhan et al., 2013; Kumari et al., 2006; Najjar and Hasan, 2008). However, recent studies have found that the efficiency of using this method can be influenced significantly by the heat transfer properties of building materials, due to a thermal-stable layer inside the north wall, which would greatly decrease the wall heat storage capacity. Based on results from simulation, Guan et al. (2014) have suggested that for a three-layer PCM wall with a thickness

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Nomenclature

Symbols
q active heat storage density (W m^{-3})
T temperature (°C)
V volume (m^3)
x coordinate or thickness (m)
y coordinate or length (m)
z coordinate or height (m)

Greek letters
c specific heat capacity (J kg^{-1} °C^{-1})
ε heat exchange effectiveness (%)
ρ density (kg m^{-3})
τ time (s)
λ thermal conductivity (W m^{-1} °C^{-1})

Subscripts
air heated air
an any level
ates east surface of air tunnel
atns north surface of air tunnel
ats surface of air tunnel
atss south surface of air tunnel
hb hollow block
in inlet
ou outlet
pb polystyrene board
PCMb phase change material wallboard
sa sand
wns north surface of wall
wss south surface of wall
ijk space grid node

Abbreviations
PCM **P**hase **C**hange **M**aterial
APTPCMW **A**ctive-**P**assive **T**riple **PCM** **W**all
PVC **P**olyvinyl **C**hloride

of 900 mm, the thermal-stable layer happened at the depth of about 650 mm, as shown in Fig. 1. Zhang et al. (2012) performed a two-year study monitoring the temperature change of a 3000 mm thick cob wall in a solar greenhouse, and suggested that the wall temperature became stable after a depth of 400 mm. Chen and Liu (2006) have developed a mathematical model to predict the temperature distribution inside the north walls, based on which they suggested that the thickness of the thermal-stable layer was 300 mm for 600 mm concrete north walls, and was 200 mm for 600 mm composite heterogeneous north walls that were made of 400 mm thick concrete and 200 mm thick slag-wool.

In order to improve heat storage capacity of the wall interior, Rodrigues and Aelenei (2010) have developed a naturally ventilated cavity wall, which helps to increase the wall interior temperature efficiently. Zalewski et al. (2012) have performed an exploration on the behavior of

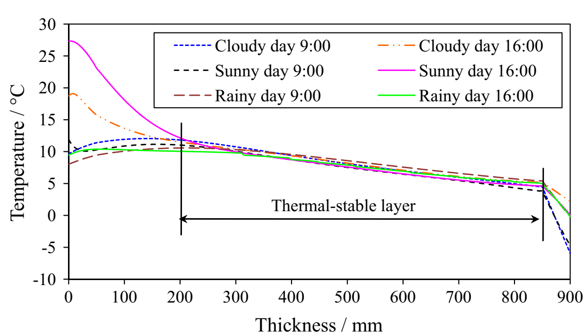

Fig. 1. Temperature distributions of a three-layer PCM wall in passive solar greenhouses.

a small-scaled Trombe composite solar wall that consisted of a double glazing layer, a non-ventilated air cavity, a heat storage layer made by PCM, a ventilated air layer and an insulating panel. From a study performed in spring, 2008, in northern France, they found that the temperature of PCM inside the composite wall could reach 52 °C. Kara and Kurnuc (2012a,b) carried out a study evaluating the thermal performance of a Trombe wall using a PCM as heat storage medium. From the study, they found that the solar energy stored by the PCM wall could cover up to 70% monthly heating load of their testing room, and up to 36% daily heating load. Chen and Liu (2004) have developed a numerical model, which can be used to analyze the distribution of airflow and temperature in theirself-developed composite wall. Using the model, they suggested that the temperature distribution inside the composite wall could be improved and the thermal resistance could be increased during the nighttime or when it was cloudy outdoors. Hassanain et al. (2011) have applied an 800 mm Trombe composite solar wall in a solar greenhouse located at the Suez-Canal University, Egypt. From field measurement, they found that when the average ambient temperature was 21.4 °C the maximum internal surface temperature of the solar wall could reach 50 °C, and the wall temperature at 400 mm depth could research 40 °C.

Generally, the north wall of solar greenhouses can absorb solar energy using two methods: the passive method and the active method. The passive method is directly absorbing the solar energy reaching the wall surface. The active method is to use solar collectors to store solar energy in some kinds of medium, such as water and air, and then use this stored energy to increase the wall heat storage