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Procedia Engineering 205 (2017) 130–136

Procedia Engineering

www.elsevier.com/locate/procedia

10th International Symposium on Heating, Ventilation and Air Conditioning, ISHVAC2017, 19-22 October 2017, Jinan, China

Thickness Determination of a Three-layer Wall with Phase Change Materials in a Chinese Solar Greenhouse

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Abstract

Chinese solar greenhouse (CSG) is an energy saving production building that used to grow vegetables in winter. The north wall of CSG plays an important role concerning the vegetable production without additional heating during the winter months. This paper studies a north wall of a CSG which is built with three layers, the phase-change material wallboard/the block brick /the insulation board. To determine the optimum thickness of the three-layer wall for passive solar heating, a solar greenhouse model is constructed by Energy Plus v8.6 to study the dynamic heat storage/release characteristics of the wall and develop methods to estimate its thickness. The results show that the optimum thicknesses of the phase-change material wallboard, the block brick and the insulation board of the expanded polystyrene in Beijing are about 50 mm, 620 mm and 60 mm, respectively. The results can provide reference for the optimization design and thermal performance analysis of solar greenhouse.

Peer-review under responsibility of the scientific committee of the 10th International Symposium on Heating, Ventilation and Air Conditioning.

Keywords: Chinese solar greenhouse; Three-layer wall; Passive solar heating; Optimum thickness; Phase change material.

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1877-7058
Peer-review under responsibility of the scientific committee of the 10th International Symposium on Heating, Ventilation and Air Conditioning.
10.1016/j.proeng.2017.09.944

1. Introduction

Chinese solar greenhouses (CSGs) are an energy saving production buildings that used to grow vegetables in winter. They are mainly located in the northern China and are characterized by passive energy storage without any auxiliary heating [1]. Comparing with the multi-span glass greenhouses, the CSGs have great advantages in term of operational cost and energy efficiency. Therefore, they have been widely used for off-season vegetable production in China. The greenhouse walls (especially the north wall) are important means of the storage for solar energy. The solar radiation is transmitted inside the greenhouse from the transparent front roof during the daytime in winter, a fraction of the transmitted radiation falls on the north wall and the radiation energy is absorbed by the north wall. According to the analysis by Ma et al. [2], the north wall of CSG can receive 26% to 37% of the total transmitted solar radiation during the daytime in winter. When the indoor air temperature decreases at night, the energy stored in the north wall can be released to improve the indoor temperature.

Guan et al. [3-4] proposed a construction method of a three-layer wall (North wall) with phase change material (PCM) used for thermal storage in CSG. The construction method of the wall is that the inner wall built with the PCM wallboard (its enthalpy is nearly 95 kJ/kg in the melting range of 7.4°C-27.5°C), the outer insulating layer is built with polystyrene board and the middle layer is built with block bricks as shown in Fig. 1. To determine the insulating layer thickness of the three-layer wall for passive solar heating, Guan et al. [5] established an analysis model of dynamic thermal performances of solar greenhouse based on Energy Plus v8.6 and an economic evaluation model. The results show that the optimum insulating layer thickness of three-layer wall for the expanded polystyrene (EPS) in Beijing region is about 60mm, but the thicknesses of the PCM wallboard layer and block brick layer have not been determined. Therefore, here we will study the thicknesses of the PCM wallboard layer and block brick layer in the three-layer wall.

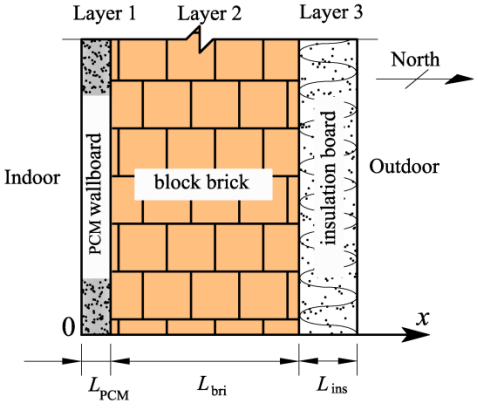

Fig. 1. Schematic drawing of the three-layer wall of CSG

2. Materials and methods

2.1. The solar greenhouse model and its validation

To determine the thicknesses of the PCM wallboard layer and block brick layer in the tree-layer wall, the solar greenhouse model by Guan et al. [5] has been used. The length, span, and ridge height of the solar greenhouse model are 27.0 m, 5.8 m and 2.9 m, respectively, and the height of the north wall is 2.3 m. The east and west end walls are built with block bricks and the thickness is 800 mm. The north wall is a three-layer wall as shown in Fig. 1. The south roof is covered with a 0.12 mm-thick ethylene vinyl-acetate copolymer (EVA) film and a 40 mm-thick insulation blanket that is retracted at 9:00 and spread over at 16:00. The solar greenhouse model has been previously validated in Ref. by Guan et al. [3, 5]. For more details on the experimental setup and results refer to Guan et al. [3, 5].