

Thermal Analysis of a Solar Wall Equipped with Photovoltaic Cells and Phase-Change Materials

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ABSTRACT: In this paper, the thermal analysis of a solar wall system equipped with photovoltaic cells and phase-change materials has been numerically investigated. For the thermal modeling of the system, the energy balance for its various components, including photovoltaic cells, air channel, absorber plate, phase-change material, and room are written. The validation of the numerical results is consistent with the experimental data of previous studies. In parametric studies, the effect of phase-change material thickness, inlet air flow rate, collector width, and packing factor have been investigated on the room temperature and system average energy efficiency in four consecutive days. Results show that the optimal phase-change material thickness is 0.05 m. Increasing the phase-change material thickness reduces the room temperature and energy efficiency. Increasing the airflow rate decreases the photovoltaic cell temperature and increases electrical efficiency, thereby increasing energy efficiency. However, it reduces room temperature. Therefore, the optimum flow rate of air was obtained at 0.04 kg/s. Increasing the collector width, despite increasing room temperature, reduces energy efficiency, so the optimum collector width was 0.7 m. The increase of the packing factor increases room temperature and reduces energy efficiency. Therefore, the optimum packing factor was 0.5.

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1. INTRODUCTION

One of the ways to optimize energy consumption in buildings is to use a solar wall. A solar wall equipped with photovoltaic cells and phase-change materials can provide electricity and heat storage throughout the day and help with space heating during the night [1]. Fig. 1 shows the schematic view of the studied solar wall.

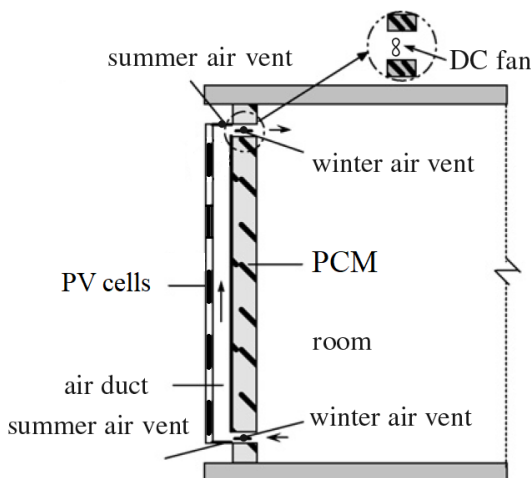


Fig. 1. Schematic view of the studied solar wall [1]

Many pieces of research [1-4] have been carried out on the performance evaluation of the solar wall system.

Jie et al. [1] investigated the thermal performance of a photovoltaic solar wall. They developed a mathematical model based on two-dimensional transient heat transfer for system various components to predict solar wall performance. Their results show that the solar wall increases the average room temperature by 0.5 °C and decreases the temperature of the photovoltaic cells by 1.28°C. In previous studies [1-4], the conventional solar wall for building heating has been studied. However, the present study analyzes the thermal performance of the solar wall, which is equipped with photovoltaic cells and phase-change material. The solar wall of the present study is capable of storing thermal energy and generating electricity simultaneously.

2. METHODOLOGY

2.1. Governing equations

The governing equations of the solar wall system are obtained by writing energy balance for the various component of the system as follows [1, 2]:

Photovoltaic cells

$$\tau_g \beta_c \alpha_c G A_g = \tau_g \eta_{el} G \beta_c A_g + U_{cond-c,g} \beta_c A_g (T_c - T_g) + h_{rad-c,sky} \beta_c A_g (T_c - T_{sky}) + h_{conv-c,a} \beta_c A_g (T_c - T_a) \quad (1)$$

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Glass cover

$$\alpha_g G(1-\beta_c)A_g + U_{cond-c,g}(T_c - T_g)\beta_c A_g + h_{rad-p,g}(T_p - T_g)A_p = h_{rad-g,sky}(T_g - T_{sky})(1-\beta_c)A_g + h_{conv-g,a}(T_g - T_a)(1-\beta_c)A_g + h_{conv-g,f}(T_g - T_f)A_g \quad (2)$$

Airflow channel

$$\dot{m}C_p \frac{dT_f}{dx} dx = [h_{conv-g,f}(T_g - T_f) + h_{conv-p,f}(T_p - T_f)] b dx \quad (3)$$

Absorber plate

$$\tau_g(1-\beta_c)\alpha_p GA_p = h_{rad-p,g}A_p(T_p - T_g) + h_{conv-p,f}A_p(T_p - T_f) + U_{cond-p,pcm}A_p(T_p - T_{pcm}) \quad (4)$$

Phase-Change Material (PCM)

$$U_{cond-p,pcm}(T_p - T_{pcm})A_p - U_{loss-pcm,r}(T_{pcm} - T_r)A_p = M_{pcm}C_{pcm} \frac{dT_{pcm}}{dt} \quad (5)$$

Air of room

$$U_{loss-pcm,r}(T_p - T_r)A_p - \dot{m}C_p T_{f,in} + \dot{m}C_p T_{f,out} - U_{loss-r,a}A_r(T_r - T_a) - U_{loss-r,w}A_w(T_r - T_{wo}) = M_r C_p \frac{dT_r}{dt} \quad (6)$$

The outer surface of the room wall

$$\alpha_w GA_w + U_{loss-r,w}(T_r - T_{wo})A_w = h_{conv,o}(T_{wo} - T_a)A_w - h_{rad-w,sky}(T_{wo} - T_{sky})A_w \quad (7)$$

The electrical efficiency of Photovoltaic (PV) cells is obtained from [5]

$$\eta_{el} = \eta_{el,ref} [1 - 0.0045(T_c - T_{a,ref}) + 0.052 \ln(G/G_{ref})] \quad (8)$$

The energy efficiency of the solar wall system is defined as follows

$$\eta_{en} = \frac{M_r C_p \frac{T_r - T_a}{\Delta t} + \frac{\eta_{el} G A_c}{0.38}}{G A_g} \quad (9)$$

2.2. Validation

The simulation results of the present study for the solar wall without phase-change material are validated with the

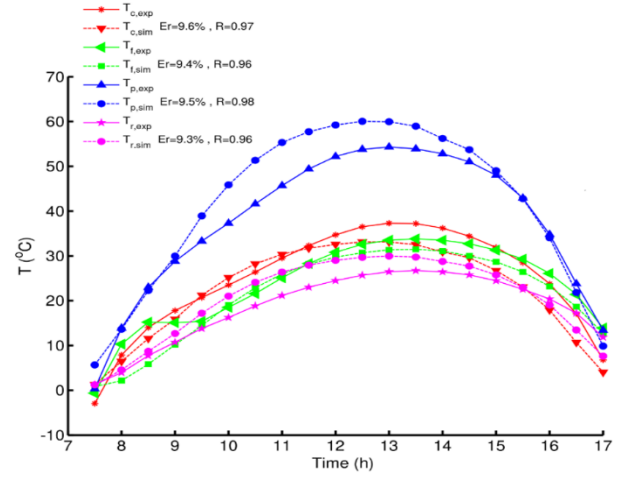


Fig. 2. Simulated and experimental values of the various temperature of the solar wall system

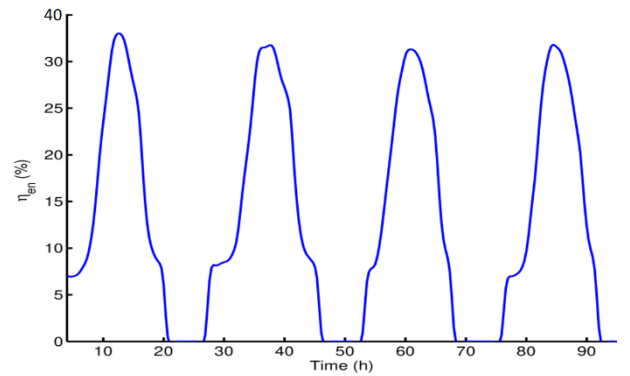


Fig. 3. Energy efficiency variations for four consecutive days

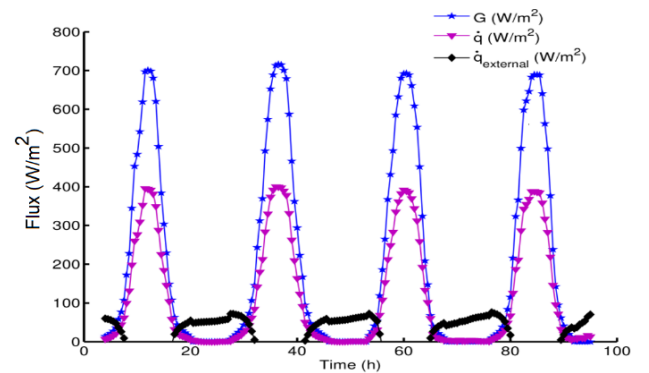


Fig. 4. Received heat flux by the room versus to solar radiation intensity and external heat flux

experimental data of Jie et al. [1] (see Fig. 2).

According to Fig. 2, the simulation results of the present study for the various temperature of the solar wall system are in good agreement with the experimental data of Jie et al. [1].

3. RESULTS AND DISCUSSION

Fig. 3 shows the variations of energy efficiency for four

consecutive days.

According to Fig. 3, the energy efficiency of the day has an upward trajectory and reaches about 35% during peak hours of sunshine. At nighttime, as the sun goes down and the ambient air gets colder, the efficiency drops sharply and reaches to near zero.

Fig. 4 shows the received heat flux by the room versus solar radiation intensity and external heat flux. The amount of heat flux received by the room is about 75% of the intensity of solar radiation. At night, the phase change material provides about 30% of the heat needed to warm the room and requires about 100 W/m² of external heat flux to fully heat the room.

4. CONCLUSIONS

It is concluded from the simulation results of the present study that the simulation results of this study are in good agreement with the experimental results of previous studies. The use of phase change material in the solar wall can provide

up to 30% of the thermal energy needed to heat the room.

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