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Performance of buildings integrated with a photovoltaic–thermal collector and phase change materials

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Abstract

To address the overheating of solar cell at midday in extreme hot summer regions as well as generate electricity with high and continuous photovoltaic efficiency, water-based photovoltaic/thermal-phase change material (PV/T-PCM) system has been proposed. A detailed simulation model for the system is presented. The effect of inlet water temperature as well as mass flow rate of the cooling water on performance parameters such as temperature of solar cell, photovoltaic efficiency is analysed. Results show that in comparison with the traditional photovoltaic panel, remarkable increase in photovoltaic efficiency has been actualized. Meanwhile, both increase in mass flow rate and decrease in inlet water temperature exert positive effect on performance parameters of PV/T-PCM system.

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Keywords: Photovoltaic thermal system with phase change material (PV/T-PCM); solar cell temperature; photovoltaic efficiency

1. Introduction

With the continuous industrialization and urbanization over the recent several decades, building energy consumption is rapidly increasing, especially in developing countries such as China 0. Meanwhile, the increasing demand for indoor environment as well as enhanced time for people spent indoors is mainly responsible for the continuous increase of building energy consumption 0. Correspondingly, an increasing number of countries and

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organizations resort to utilizing renewable energy 0. As a typical renewable energy, solar energy has recently attracted public attention because of its environmental friendliness, easy accessibility and high availability 0. As an indispensable component in the solar energy utilization technologies, photovoltaic cell directly converts solar radiation into electrical energy because the electrons are released by semiconducting materials after absorbing photons from sunlight. However, the photovoltaic efficiency shows negative correlation with the solar temperature, i.e. photovoltaic efficiency would be decreased by 0.4% every 1°C rise in solar cell temperature 0. In this sense, decreasing the solar cell temperature at midday will definitely increase photovoltaic efficiency, thus increasing electrical generation. Being able to absorb substantial heat energy with neglected temperature change, PCMs have increasingly attracted researches' attention in terms of mitigating the solar cell temperature via being integrated passively or actively 0.

From the available literature, previous studies mainly focused on PCMs being passively integrated in photovoltaic (PV) system. Smith et al. 0 analyzed the increase of annual energy output actualized by PCM embedded PV system from a global perspective. Hasan et al. 0 experimentally studied the impact of PCM layer on electrical efficiency of PV and thermal energy efficiency of indoor environment. The PV power output would be increased by 7.2% at peak and 5% on average along with enhanced indoors cooling effect of 9.5% at peak and 7% on daytime average. After realizing that the low thermal conductivity and crystallization segregation of PCM greatly limited their effectiveness in controlling temperature rise in PV, Huang et al. 0 have proposed different internal fins arrangements in the PV/PCM system and concluded that internal fins enhanced heat transfer and improved the temperature control of the PV in PV/PCM system.

However, many problems can't still be addressed in the above proposed system, such as overheating of exposed surface in the PV/T system and low electrical efficiency at midday. Moreover, a large discrepancy between supply and demand would appear as heat demand is the maximum in the evening while the solar radiation intensity is nearly zero 0. In this sense, the photovoltaic/thermal-phase change material (PV/T-PCM) system has been proposed. On the one hand, PCM absorbs the heat from solar thermal collector to prevent overheating of photovoltaic, ensuring the improved electrical generation efficiency because of the decreased average temperature of photovoltaics. On the other hand, the integration of PCM-based thermal energy storage is able to store large quantity of heat via phase transition for later use, making it possible for continuous electricity generation. The principal purposes of this study are: (1) to develop an experimentally validated mathematical model to analyze the dynamic photovoltaic and thermal performances of the water-based PV/T-PCM system. (2) to investigate the effect of inlet water temperature as well as its mass flow rate on both thermal and electrical performance of PV/T-PCM.

Nomenclature

λ	thermal conductivity(W/m K)
h	convective heat transfer coefficient(W/(m^2 °C))
I	solar radiation intensity (W/m^2)
Nu	Nusslet number
Ra	Rayleigh number
η	photovoltaic efficiency
α	absorptivity
ε	transmittance
σ	Stefan-Boltzmann constant (W/(m^2 °C^4))
ρ	density (kg/m^3)
c	specific heat capacity (J/(kg °C))
T	temperature (°C)
δ	thickness (m)
v	air flow rate (m/s)
F	packing factor
τ	transmissivity
Q_p	photovoltaic power (W)