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Preliminary performance test of a combined solar thermal roof system with heat pump for buildings

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Abstract

In the present study, a novel solar thermal roof collector was developed by primarily exploiting components and techniques widely available on the market and coupled with a commercial heat pump unit. The proposed indirect series solar-assisted heat pump system was experimentally tested and preliminary system performance was investigated. Yet, the analysis based on indoor and outdoor testing predominantly focuses on the solar thermal roof collector. A detailed thermal model was developed to describe the system operation. Also, a computer model was set-up by using Engineering Equation Solver (EES) to carry out the numerical computations of the governing equations. Preliminary analyses show that the difference in water temperature could reach up to 18°C while maximum thermal efficiency found to be 26%. Data processing of the series covering the test period represents that Coefficient Performance of the heat pump (COP_{HP}) and overall system (COP_{SYS}) averages were attained as COP_{HP}=3.01 and COP_{SYS}=2.29, respectively.

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Keywords: Solar thermal roof collector; polyethylene heat exchanger; heat pump; energy analysis

1. Introduction

Combination of the heat pump and solar energy is a mutual beneficial way of enhancing the coefficient of performance of a heat pump and solar collector efficiency. The heat pump COP can be elevated to the great extent on the temperature of the evaporator. The solar collector loop enables to boost the heat source temperature of the heat pump, thereby improving the annual and seasonal performance of the heat pump [1]. By integrating unique

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polyethylene heat exchanger loop into a novel roof construction to form a "Sandwich" Thermal Roof Collector could be an efficient alternative to conventional solar thermal collectors to maximize the solar heat energy absorption.

The objective of this study is to investigate a roof integrated thermal "Sandwich" solar thermal roof collector that properly blends into surrounding thus avoiding 'add on' appearance and having a dual function (heat absorption and roofing) with heat pump. The present study will both theoretically and experimentally evaluate the thermal performance of the "Sandwich" roof unit with heat pump.

Nomenclature

A_{eff}	Effective area, m²	ϭ	Stefan-Boltzmann constant
C	Specific heat	ζ	transmittance
COP	Coefficient of Performance	*Subscripts*	
D_i	inner diameter of heat exchanger tube, m	*a*	ambient air
D_o	Outer diameter of heat exchanger tube, m	*abs*	absorber surface
e	Percent deviation	*c*	cover layer
F	Collector efficiency factor	*cp, e*	electrical energy in compressor
G_r	Grashoff number	*cs*	collector side
g	Gravitational acceleration, m/s²	*c, t*	thermal energy in condenser
h	Heat transfer coefficient, W/m²K	*cv*	convective
H	Enthalpy, kJ/kg	*e*	evaporator
I	Incident solar radiation, W/m²	*e, t*	thermal energy from evaporator
K	Thermal conductivity, W/m.K	*f*	fluid
m	variable defined to solve differential equations	*he*	heat exchanger
$\dot{m}$	Mean flow rate, m/s	*hein*	inner wall of heat exchanger
Nu	Nusselt number	*heo*	outer wall of heat exchanger
Q	Energy, W	*heo, hein*	outer wall to inner wall of heat exch
T	Temperature, °C	*hein, r*	inner wall of heat exch to refrigerant
U	Thermal transfer coefficient, W/m²K	*HP*	heat pump
W	Distance between tubes, m	*l*	loss
$\dot{W}$	Compressor power, W	*ls*	load side
V	Wind speed, m/s	*p*	pipe
Greek Letters		*r*	refrigerant
α	absorption	*rd*	radiative
δ	thickness, m	*s*	sky
ε	emissivity	*SYS*	system
η	efficiency, %	*t*	thermal
λ	thermal conductivity, W/m.K	*t, net*	net thermal
Σ	total	*u*	useful
ρ	density, kg/m³	*w*	water

2. Novel thermal roof structure combined with heat pump

The system consists of a Thermal "Sandwich" Roof collector that can act as both roof element and low grade heat source for the heat pump. The roof module contains several layers, namely the outer surface is a black painted aluminum solar radiation absorber, polyethylene heat exchanger loop tightly screwed to the black aluminum surface for enhanced heat transfer and injected insulation foam back layer against heat loss. Furthermore, thermally conducting adhesion was used to improve the heat transfer between the aluminum cover and poly heat exchanger pipes. By this means, all layers are integrated into the same module to form a "Sandwich" Thermal Roof collector. Fig. 1 is the illustration of layers of "Sandwich" thermal roof collector.