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ScienceDirect

Energy Procedia 123 (2017) 180–187

Energy Procedia

www.elsevier.com/locate/procedia

1st International Conference on Sustainable Energy and Resource Use in Food Chains, ICSEF 2017, 19-20 April 2017, Berkshire, UK

Indirect expansion solar assisted heat pump system for hot water production with latent heat storage and applicable control strategy

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Abstract

Integration of renewable energy with energy conversion application for hot water production is a significant technology to be studied for industrial, commercial and residential proposes. It has been further enhanced since the international energy agency (IEA) puts effort to standardize such kind of technology. In this paper, a novel study has been carried out experimentally to control an indirect solar assisted heat pump (IDX-SAHP) system integrated with a latent heat storage (PCM) tank. The PCM heat exchanger tank was designed specially and controlled automatically which allowed storing excess energy during the day and releasing it when needed. In addition, a system control strategy has been purposely designed and implemented in a Building Management System (BMS) to ensure the stable and reliable system operations. The experimental results show that the PCM heat exchanger tank installation has a significant effect on the system operation stability and can improve the COP of the IDX-SAHP system at different weather conditions and a specified hot water load profile.

Peer-review under responsibility of the scientific committee of the 1st International Conference on Sustainable Energy and Resource Use in Food Chains.

Keywords: IDX-SAHP system; PCM tank; control strategy experiment; system stability and efficiency

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1876-6102
Peer-review under responsibility of the scientific committee of the 1st International Conference on Sustainable Energy and Resource Use in Food Chains.
10.1016/j.egypro.2017.07.258

Nomenclature

Cp	Specific heat capacity (J kg^{-1} K^{-1})	*Subscripts*	
H	Enthalpy (J kg^{-1})	comp	Compressor
$\dot{m}$	Mass flow rate (kg s^{-1})	*h*	Heating
Q	Heat transfer rate (W)	ref	Refrigerant
T	Temperature (^{0}C)	*sys*	System
ΔT	Temperature difference (K)	*w*	Water
Q	Heat transfer rate (W)	*wfc*	Water fan cooler
W	Work input (W)		

1. Introduction

Due to the extensive consumption of fossil fuel in heating purposes in the UK, meeting CO_2 emission reduction target remains a challenge for the country if alternative energy resources or technologies for heating cannot be applied. The heating demand can be met by green technologies and advanced systems such as a solar thermal, air-water heat pump, geothermal heat pump and their integrations. Solar domestic water heaters (SDWHs) have been increasing in popularity in the UK and other countries worldwide and can greatly save energy for water heating in the summer [1]. However, the large temperature difference between the solar collector and ambient temperatures during winter has greatly reduced system performance such that assistant heaters such as gas, wood boilers or electric heaters must be added [2, 3]. The air source heat pump water heaters are compact, simpler and economic but also work less efficiently over the cold winter period [4]. Alternative substitutes such as Solar Assisted Heat Pump (SAHP) system has been deemed the more feasible option when taking into consideration important factors such as cost, application area limitation and constant water heating production etc. [5]

The combination of solar energy and heat pump technology can be classified into two categories: direct expansion solar assisted heat pump (DX-SAHP) and indirect expansion solar assisted heat pump (IDX-SAHP) [6]. For a DX-SAHP system, the solar collector also acts as the evaporator of the heat pump unit, thereby making the system more compact but requiring greater heat pump working fluid charge [7]. In addition, when there is insufficient solar radiation, the solar collector/evaporator cannot absorb enough heat required by the heat pump and thus negatively affect system performance [8]. On the other hand, with an IDX-SAHP system, solar radiation transfers heat to water flow through the solar collector and then provides heat to the heat pump evaporator. In such circumstances, the working fluid charge in the heat pump can be greatly reduced. The IDX-SAHP can also be further classified into three design layouts based on different heat source arrangements: series, parallel and dual source. For a series IDX-SAHP system, the solar energy is collected by a solar collector and stored in a water storage tank which is used as the only heat source for the heat pump. Solar heat sources may be insufficient for meeting building heating demands in certain weather conditions and time periods. A SAHP system used for mushroom drying was experimented which was relatively similar to the series IDX-SAHP scheme for space heating [9].

For a parallel IDX-SAHP system, a conventional solar system operates in parallel with an air source heat pump such that the heat pump operation is independent of solar energy availability. Therefore, the building heating load can be met by either the solar energy or air source heat pump. A parallel SAHP system was simulated and compared the system performances with both ground and air source heat pumps [10]. The ground source heat pump appeared promising in terms of absolute electricity saving when paralleled with solar energy.

In this paper, a new IDX-SAHP test system was designed, installed and instrumented. A PCM storage heat exchanger tank and an air-source heat exchanger were purposely built and installed in the system solar thermal loop and connected to the heat pump evaporator. Subsequently, the heat source from either solar energy or ambient air can be applied for the heat pump. In addition, a control strategy for the system was purposely designed and implemented so as to determine the optimal operation of the IDX-SAHP system. Comprehensive experimental investigations were carried out in the test rig to evaluate and compare system operation and performance in different weather conditions and structures with and without PCM tank installations. The research outcomes can lead to the optimisation of future system designs and controls [11].