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Solar assisted heat pump systems for low temperature water heating applications: A systematic review

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ABSTRACT

Combination of solar thermal collectors and heat pumps in a single solar assisted heat pump (SAHP) system has been widely used for various purposes including water heating. International Energy Agency, Task 44 of the Solar Heating and Cooling (SHC) Programme, has been working on methods towards most effective use of solar heat pump systems for residential use. The current work aims at reviewing the past and present work conducted on the SAHP systems for low temperature water heating applications. The review approach is based on a visualisation scheme to systematically represent and classify concepts of SAHP systems. Specifically, the key performance data from a number of studies are highlighted and various configurations are compared in order to gain accurate and deep intuitive understanding of SAHP systems. The review faithfully states that having a variety of configurations, parameters and performance criteria may lead to a major inconsistency that increase the degree of complexity to compare and analyse the studies of different systems.

Contents

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1. Introduction

Global energy consumption has increased substantially in recent decades. Conventional fossil fuel based energy sources cover a large portion of the worldwide energy use. In 2008, the total global energy consumption was about 17 TW ($=1.7\times10^{13}$) with 81.4% from fossil fuels [1]. However, burning or combusting fossil fuels causes global warming as a result of greenhouse effect, air pollution, and acid rain by depleting carbon dioxide and other harmful gases to the environment [2]. Since 1750, 31% increase in the atmospheric concentration of CO_2, above pre-industrial level, is noted while fossil energy consumption has increased most in 2000–2008. This growing demand for fossil fuels may cause a major disruption and endanger the energy supply chain. The major concerns of depletion in fossil fuel based energy sources, economic and environmental problems associated with the combustion of fossil fuels have led to the critical societal need to transition to renewable energy resources such as solar, wind, and hydropower in recent years [3].

In 2013, UK's total energy consumption was 205.9 million tonnes of oil equivalent (mtoe). About 31.7% of this total energy was consumed in domestic applications. Space heating alone accounts for 53% of the energy consumed in a typical UK household while it is estimated that about 13.7% is for low temperature (<80 °C) water heating applications in which energy demand is primarily satisfied through either natural gas or electrical heaters [4]. However, use of conventional source of energy based systems leads to increased greenhouse gas emissions into the atmosphere. A typical natural gas water heater releases around 2 t CO_2 annually. Electric hot water systems are having more harmful effect for about three times the emission of CO_2 for each kWh of electrical energy, compared to natural gas water heaters. In spite of low capital cost of this fossil fuel based systems, due to implicit environmental cost for remedy or separation of CO_2 fossil fuel burners it is worth the time, money or effort to search for less expensive, environmentally friendly alternatives such as solar energy, one of the most viable renewable based energy sources [3].

A solar-assisted heat pump system (SAHP) is a particular technique to reduce or eliminate the primary energy (coal, natural gas, etc.) consumption through substitution of renewable based energy sources to achieve reduced CO_2 emission. The system is able to convert and transport thermal energy from the sun to water or working medium or absorbers. In addition, this system allows transferring heat for storage purposes. Through modification in the system configuration, reduction in the number of system units and cost, and enhancement in efficiencies would be achievable. There has been a growing interest for such hybrid systems with a variety of system configurations for various climate conditions. A number of research studies have been presented in the literature on fundamentals of system design, modelling and optimisation of performance characteristics, as well as experimental investigations of pilot scale designs [5]. The main objective of this study is to present a systematic review of the research and developments on solar assisted heat pump systems for low temperature water heating applications. This study is, therefore, arranged into three main parts as follows:

- Solar assisted heat pumps and low temperature heating applications
- Design components and configurations
- Thermal performance characteristics of SAHP

2. Classification method

There are different types of system classifications designed in various categories. Solar assisted heat pump systems can be classified by the type of applied components like collector types, flat plate, glazed-unglazed etc. or alternatively type of refrigerant used in the heat pump cycle. However, the efficiency of such systems immensely depends on environmental conditions, system and component size and load characteristics. Therefore, there would not be any simple classification method to conform the public to an easy communication. Yet, these various specifications, in literature, to compare the SAHP systems are systematically shown by Frank et al. [6]. A comprehensive table that displays research, design and development work and an overview of design approach such as refrigerant type, with or without storage, the location of the storage, can indicate particular know-how about solar heat pump applications. Hence, a methodical display in Table 1 was presented from literature including system information and boundary conditions regarding climate.

3. Systematic visualisation scheme of solar assisted heat pump concepts

System classification for various solar assisted heat pump concepts is performed by considering distinctive system configuration features like collector type, heat sink of the system, storage concept etc. The table presented in Section 2 provides a piece of information for a plain classification method. In the energy flow like visualisation scheme, only solar assisted heat pump system is illustrated rather than a whole building. As a result of analysing many combined solar and heat pump systems, it is found that solar assisted heat pumps systems comprise five recurring components namely solar collector, heat pump and backup heater, along with storages either cold or load or both side of the heat pump units. Fixed positions for all these components are defined although specifications, like type of the collector, may vary in different configurations.

Assorted colours used in the visualisation scheme distinguish the energy flow in the system as final (grey), boundaries (grey background), environmental energy (green), useful energy (red), energy converters (orange) and storages (blue). Yet colouring is an additional feature as it is not essential to comprehend the concept. The final energy (to be purchased such as electricity) is shown at the system boundary on the left-hand side where useful energy (i.e. domestic hot water-DHW) flow is introduced on the right. Environmental energy sources enter the system from the top while any losses would be downwards although no losses leaving the system depicted as being redundant to system characterisation. Lastly, the connection of system components is illustrated to analyse and compare the concepts. Each line style aims at the carrier medium, excluding driving energies mostly without mass i.e. solar radiation.

One should remark that all potential operating modes of one combined solar and heat pump system is presented simultaneously by one flow chart visualisation. All components in a solar heat pump concept are depicted as filled; others remain shaded as placeholders for orientation and comparison purposes.

A simple example of a visualisation scheme is provided in Fig. 1 to comprehend the classification method. In Figs 2–4, widely available combined solar and heat pump configurations are presented