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Exergetic assessment of direct-expansion solar-assisted heat pump systems: Review and modeling

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Abstract

Although the idea of using a solar collector as the evaporator in the traditional heat pump cycle was first proposed in the year 1955, studies on the subject began in the late 70s. One of the keystones for obtaining sustainable development is also the use of exergy analysis. In this regard, the main objectives in doing the present study are twofold, namely (i) to review studies on direct-expansion solar-assisted heat pump systems (DX-SAHPs) and (ii) to present a mathematical model along with an illustrative example, which is used for heating an office space in Solar Energy Institute of Ege University, Izmir, Turkey, by floor heating with a DX-SAHP system. The system uses a 4 m^2 bare flat-plate collector as the evaporator, while the working fluid is chosen to be R-22. Water is heated by the heat pump and heat is delivered to the office space by floor heating. Exergy equations for the system are derived, while exergy calculations are made. The exergy efficiency values for the individual components of the DX-SAHP system are found to range from 10.74% to 88.87%. It is expected that this study will be very beneficial to everyone involved or interested in the exergetic design, analysis and performance assessment of DX-SAHPs.
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Keywords: Exergy analysis; Direct expansion; Solar-assisted heat pump; Sustainability

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Contents

1. Introduction

Energy consumption plays the major role in the overall budget in many countries. Domestic consumption of energy mainly occurs in hot water production and space heating. Sources for energy used generally in these applications are mainly fossil fuels. Using renewable energy sources, mainly solar energy, for especially domestic applications may be the key to reduce energy costs and consequently the amount of energy costs within the whole country budget, while providing sustainable development.

Heat pump systems are heat-generating devices that can be used to heat water to be used in either domestic hot water or space heating applications. For heat pumps, a basic factor of great importance for its successful application is the availability of a cheap, dependable heat source for the evaporator—preferably one at relatively high temperature. The coefficients of performance (COP) of heat pump systems depend on many factors, such as the temperature of low-energy source, the temperature of delivered useful heat, the working medium used, the characteristics of components of heat pump systems, etc. Among the above mentioned, the temperature of the evaporator is a key factor [1].

In order to improve the heat pump COP_H for heating and displace the fossil energy resource, the idea of combining the heat pump and solar energy in mutual beneficial ways has been proposed and developed by several researchers [2–5]. In a typical solar-assisted heat pump (SAHP), the closed loop of the solar collector mainly uses water or air as the working fluid and is separated from the heat pump evaporator. In a direct-expansion SAHP (DX-SAHP), the collector and evaporator functions are combined into one unit, where the refrigerant from the condenser gets evaporated by incident solar energy [6].

The main objectives in doing the present study are to: (i) review studies that have been conducted on DX-SAHP systems taking into consideration the analysis that have been made (theoretical–experimental, energy–exergy) and the utilization of the systems (space heating, water heating, air conditioning (A/C)), (ii) present a mathematical model for exergy-based DX-SAHP calculations including thermodynamic parameters such as fuel depletion ratio, relative irreversibility, productivity lack and exergetic factor as well as improvement potential and (iii) apply the presented mathematical model to an illustrative example.

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