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Design and optimisation of dual-mode heat pump systems using natural fluids

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ABSTRACT

The paper introduces new multi-period modelling and design methodology for dual-mode heat pumps using natural fluids. First, a mathematical model is developed to capture thermodynamic and operating characteristics of dual-mode heat pump systems, subject to different ambient temperatures. The multi-period optimisation framework has been developed to reflect different ambient conditions and its influences on heat pump performance, as well as to determine a system capacity of heat pump which allows systematic economic trade-offs between supplementary heating (or cooling) and operating cost for heat pump. Case study considering three geographical locations with different heating and cooling demands is presented to illustrate the importance of using multi-period optimisation for the design of heat pump systems.

1. Introduction

Due to increasing fuel costs and stricter environmental regulations, heat pump systems using renewable sources have gained great interests as one of practical and realistic solutions in the near future to save energy consumptions as well as to reduce CO_2 emissions to the environment. For an example of an assessment, see e.g. by the EC [1]. Replacing conventional fossil fuels with cleaner renewable energy sources can reduce the amount of CO_2 emissions related to the usage of fossil fuels in traditional heat pump systems. The heat pumps applications have been reviewed elsewhere e.g. [2]. They have been under development with various related special features, including micro and compact heat exchangers in [3] or hybrid heat pumps in combination with heat storage [4].

Both cooling in the summer and heating in the winter are required in many geographical areas, where a dual-mode heat pump system is often employed. With dual-mode operation for heat pump systems, heat is extracted from the heat source in the winter, and is circulated into the home, while, during the summer, heat is drawn from the interior air and rejected to the heat sink. Heat sources and sinks for residential heat pump applications can be ground surrounding a building, water in lakes, rivers or wells, and outdoor air. An air-source heat pump is considered in this paper as this is the one of most common types of heat pumps.

The appropriate sizing of system elements in the heat pump application is extremely important in order to achieve minimum cost and maintain high energy efficiency. The thermal performance of heat pump systems heavily depends on operating conditions. But operating conditions in residential air-source heat pumps varies with ambient conditions. Therefore, the heat pump performance at the nominated design conditions should not be only a criterion for assessing whether a heat pump is properly designed, as the heat pump is not operated at the design condition for all the time.

Various climate conditions had been considered for the optimal design of reversible heat pump systems – for air–water [5], air–air [6] water–water [7], hybrid [4], space heating and cooling [8]. Optimisation study was carried out to the air-sourced heat pump for water heating was addressed to improve the system performance of COP [5]. Optimum design was also sought to analyze reversible heat pumps for air-to-air systems [6], water-to-water systems [7] and ground-to-air systems [4,8]. The effect of climatic conditions on ground-sourced heat pump systems was discussed and its significance for the design of heat pump systems was addressed [8]. However, there are still lacks of systematic approaches which optimise dual-mode heat pump systems with considering simultaneously non-steady ambient conditions. A heat pump is often selected such that its output balances the heat requirement of the building in most ambient conditions [9]. This 'rule of thumb', however, does not guarantee a minimum cost or

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