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Analysis of a wall cooling system using a heat pump

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ABSTRACT

In this study, a vertical ground source heat pump wall cooling system that belongs to the Yıldız Renewable Energy House at the Davutpaşa Campus of Yıldız Technical University was studied both experimentally and theoretically. The principal objective was to perform a system analysis to determine the parameters that allow the energy usage of the cooling system to be as low as possible. For this reason, a system working in a low temperature regime was chosen. The examination includes energy and exergy analyses conducted during the period between 1 July and 30 September 2012, which is described as the "Summer Session". By using the data that were collected on a per-second basis during these processes and conveyed to a MySQL database, "The moments when the heat pump is activated" were detected, and the "Monthly Average Values" were analyzed. Thus, a theoretical analysis was conducted for the Cooling Session and its correlations. These correlations were used in the energy and exergy analyses. According to the analysis results, the energy and exergy efficiencies of the entire system were found to be 74.85% and 29.90%, respectively, and the Wall Heating Cooling System panels calculated the heat with energy and exergy efficiencies of 90.29% and 80.4%, respectively.

1. Introduction

One of the most important problems today is energy sources and their usage. It is clear that the world cannot meet the needs of its rapidly growing population in the near future with its limited and rapidly depleting energy sources. The main issues of energy are thus not only the amount of energy but also its quality. Using energy in an efficient and effective way has become an indispensable necessity for the world. At the same time, during the production and consumption of the energy, the damage caused to the environment must be kept to a minimum. For this purpose, alternative technologies along with renewable energy sources must be developed, and some work must be done to allow these systems to be used, particularly in the residential sector [1], in industry and in daily life. In this regard, Heat pumps (HPs) are noteworthy technologies that use to extract energy from renewable energy sources, such as, Ground Source Heat Pumps (GSHPs), Solar Energy Assisted Heat Pumps, Geothermal Source Heat Pumps, and Water Source Heat Pumps etc.

In the open literature, many studies are available on GSHPs. The studies performed within this framework may be grouped as design, performance, economic analysis, testing, business experience and others. Sarbu and Sebarchievici performed a detailed literature review of GSHP technology, concentrating on ground-coupled HP systems. Initially, the operation principle and energy efficiency of a heat pump were defined [2]. Fan et al. [3] designed a GSHP test system among four experimental sites for a 500 m^2 building in Shanghai, China, which is a cooling-load-dominated area. A theoretical analysis using the TRNSYS software and elementary experimental research was performed to determine the influence of various factors on the soil heat imbalance and system operation efficiency. Yang et al. [4] proposed an updated method for the dynamic simulation of a GSHP system. The method developed an analytical heat transfer model for a borehole heat exchanger (BHE) considering the variation of fluid temperature along the borehole length and the thermal interference between two adjacent legs of a U-tube. Based on the BHE model, the borehole heat exchange effectiveness (BHEE) was put forward and defined, and the influences of borehole thermal resistance, fluid thermal capacity and borehole depth on the BHEE were investigated.

Many research studies are available on the performance of GSHPs. Several of these studies are simulation studies. First law

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analyses are studies that begin as thermodynamic analyses, whereas optimization studies demonstrate the development of hybrid systems via optimization.

The comparison of the energy performances of air sourced HP and GSHP in typical Mediterranean climate regions was performed by Urchueguía et al. [5]. In their study, the technical and economic feasibility of its usage was evaluated. Hepbaşlı et al. [6–8] performed COP energy and exergy analysis of a GSHP system with 50-m vertical drilling applied to a 65 m^2 classroom with passive heating and air conditioning features in the Sun Energy Institute. Dikici et al. [9] carried out a study on the performance analysis and energy–exergy equivalence of a solar energy-aided HP system. Özgener and Hepbasli [10–13] acquired exergy efficiency results for a solar energy aided vertical GSHP and a combined system, respectively, for greenhouse heating under the reference temperature of 10.93 °C. Bilgen and Takahashi [14] performed exergy analyses of heat pump systems and examined the irreversibility due to heat transfer and friction. Esen et al. [15] examined the energy and exergy efficiencies of a GSHP in which a vertical ground heat exchanger was used. Lohani and Schmidt [16] compared the energy and exergy efficiencies of an air source heat pump. Bi et al. [17] performed a comparative exergy analysis of a ground source heat pump (ground circuit, heat pump and location circuit cycles) for the heating and cooling periods. The results showed that the maximum exergy loss rate was found in the compressor and that the minimum exergy efficiency was found in the ground heat exchanger of the whole system. Zeng et al. [18] examined the performances of vertical underground heat exchangers, and İnallı et al. [19] examined the performance of horizontal underground heat exchangers. Yang et al. [20] examined the relationship among the pipe diameters of a serpentine buried in the ground in a GSHP system, the operating time of the system and the change in the soil temperature around the serpentine. Currently, with the reduction of available energy sources, increase in energy prices and increasing environmental awareness in society, both interest and studies on the residential and industrial usage of GSHP technology in European, American and Asian countries have increased.

GSHPs form an ideal system that can meet the energy needs of heating and cooling systems that work with particularly low-temperature energy sources and can provide comfort conditions such as radiant systems, specifically Wall Heating and Cooling Systems (WHCS). Due to their environmental friendliness and the ever-increasing prices of fossil fuels, GSHP systems will only increase in popularity.

Radiant systems are used for both heating and cooling in walls, floors and ceilings. These systems provide the desired thermal comfort conditions in the environment through serpentines embedded in the wall, floor or ceiling through which hot/cold fluid passes. Because they provide comfortable conditions but require quite low energy compared with conventional air-conditioning systems, they are suitable for use along with heat pump systems. In the literature, studies related to system design and calculating the transferred heat in wall cooling systems are available. In this context, Myhre and Holmberg [21], in their study on indoor thermal climates, analyzed two office models using simulations. Offices were heated with four different heating systems: a floor heating system, two types of radiators and a wall heating system. Aldawi et al. [22] compared the thermal performances of two house wall systems with single and double glazed windows under variable climate conditions. The study was undertaken using the thermal performance simulation software AccuRate®. The findings indicate that significant energy savings can be achieved using the new house wall system compared with the currently used brick veneer house wall system.

Karabay et al. [23] numerically investigated a comparative evaluation between a floor heating system and a wall heating system for Kocaeli province with an outdoor design temperature of −3 °C. Computations were performed for three different water temperatures: 30 °C, 40 °C and 50 °C. The main purpose of the study by Acıkgöz et al. [24] was to numerically investigate the effects of the hot and cold wall temperatures of a room and the characteristic length on the average CHTC for an enclosure using both two- and three-dimensional models. Feustel [25] examined many studies on hydronic radiant cooling. Compared with convective cooling systems, radiant cooling systems are more advantageous because of their homogeneous air temperature distribution in the environment and the heat exchange between the environment and the human body. Imanari [26] compared a radiant roof panel system and a convective air conditioning system in terms of thermal comfort, energy consumption and cost. He stated that the radiant roof panel system provides lower average air velocity and higher thermal comfort for a low air flow system. Vangtook and Chirarattanano [27,28] performed experimental and simulation studies on a radiant cooling system that was used along with natural ventilation in hot and very humid areas.

The development of WHCS technology continues to be parallel with developments in semi-rigid, flexible polymeric pipe material. In these systems, cross-linked polyethylene pipes known as PEX are used. PEX pipes are non-toxic and lead-free, and unlike pipes made of copper and other materials, they have no harmful effect on temperature transfer flow. The heating and cooling are provided using panels in the shape of a grid or serpentine mounted on the walls of the buildings (Fig. 1). After the panels are mounted on the wall, they are covered with gypsum plaster, and the normal wall image is produced. Thermopiles or temperature gauges installed where the pipes pass through the walls can monitor the system performance.

A WHCS can be operated with a single-zone, constant temperature, constant air volume, central forced ventilation system, with a dual channel, re-heated, multi-zoned or variable volume system, or with decentralized convective systems and inter-spot fan-coil terminal units [21].

When a cooling system is used with the wall heating system, water at a temperature of 18–20 °C is passed through the pipes to provide heating instead of cooling. For the conditions of İstanbul, the spot temperature is taken as 24 °C, the relative humidity is 55%, and the dew point temperature is 14 °C. Because the wall temperature does not fall in this temperature range, humidity is not released to the walls [29].

There is more than one alternative in the replacement of conventional systems with renewable energy systems. To make a proper selection, it is necessary to perform energy and exergy analyses. In the literature, there has thus far been no report on the detailed energy and exergy analysis of a GSHP-aided wall cooling system. The available studies generally analyze the temperature transfer in wall cooling systems using energy and exergy analyses of GSHP systems.

In this study, energy and exergy analyses of wall cooling systems fed by vertical-type ground source heat pump used for cooling are performed. In this context, the energy and exergy circuits for the defined elements of the system are first calculated. According to the information obtained in the conclusion of the review literature, the element with the lowest exergy efficiency in the soil source heat pump systems is the compressor. The highest exergy destruction should occur in this element.

2. Methodology

This study was conducted in a location prepared in the context of a project named “The modeling and analysis of compound