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Research Paper

Energetic and financial evaluation of a solar assisted heat pump heating system with other usual heating systems in Athens

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HIGHLIGHTS

- A solar assisted heat pump heating system is compared with other heating systems.
- An air source heat pump and a solar assisted system with fan coils are these systems.
- The air source heat pump heating system is the most feasible system financially.
- The solar assisted heat pump heating system consumes the less electricity.
- Solar assisted heat pump system leads to the best indoor temperature profile.

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ABSTRACT

This study is a manifold energetic and financial comparison of various heating systems. The examined building is a well-insulated building of 100 m^2 area located in Athens (Greece) and three different heating systems are investigated in order to determine the most suitable technology. The basic idea of this study is to compare a solar driven heat pump space heating system with an air source heat pump heating system and a fan coil heating system driven by solar collectors with an auxiliary electrical heater. Feeding a heat pump with hot water increases the Coefficient of Performance (C.O.P.) because the heat source temperature is higher compared to the case of air source heat pump. The energetic simulation tool of the analysis is the commercial software TRNSYS which simulates the behavior of complex transient systems. Many combinations of collecting area and storage tank volumes are presented because these are the main parameters which influence on a solar heating system performance. A simple sensitivity analysis proved that 25 m^2 flat plate collectors (FPC) coupled with a storage tank of 1 m^3 are able to feed the heat pump while 40 m^2 of solar collectors coupled with a 1.25 m^3 storage tank lead to solar coverage over 70%. Every system is designed carefully in order to maintain the thermal comfort conditions in high standards. The last part of this analysis is the financial evaluation of the examined technologies in terms of total cost which combines the investment and the operation cost.

1. Introduction

The new lifestyle trends lead our society in higher energy consumption in order to achieve the higher thermal comforts standards. One third of the global energy consumption that is used in the building sector represents a high amount of energy [1–3]. The last years the accelerated increase in fossil fuel cost and in the electricity tariffs have leaded the yearly cost of space heating in high levels. Thus, new and innovative ways are applied to reduce the operating cost and to create lower cost heating systems, affordable to the majority of the society. The use of alternative energy sources, such as solar energy, geothermal energy and waste heat, are very promising sources to cover partially or totally the energy demands of buildings. Solar energy utilization for space heating consist of an efficient and simple way to cover the building loads in a high fraction.

In countries with high radiation levels and simultaneously high heating loads in winter, solar heating technologies are the most proper technology among the unconventional heating systems. In Greece, the solar radiation potential varies from 1400 kW h/m^2year in Macedonia to 1800 kW h/m^2year in Crete [4], with Athens to have an intermediate value at 1600 kW h/m^2year [5]. Moreover, the specific heating energy demand is approximately 25 kW h/m^2 in Crete, 37 kW h/m^2 for Athens and 58 kW h/m^2 for Macedonia [6]. It is obvious that Athens is the city in Greece which combines

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Nomenclature

A_{col}	collecting area, m^2
COP	coefficient of performance
c_p	specific heat capacity, kJ/kg K
C_0	capital cost, €
C_1	variable cost, €
f	solar coverage
F_R	heat removal factor
H	daily solar radiation on horizontal surface, kW h/m^2
k	thermal conductivity, W/m K
N	project life time, years
T	temperature, °C
P_{el}	electricity consumption, kW h
Q	energy, kW h
r	discount factor
U	thermal transmittance, W/(m^2 K)
U_L	thermal loss coefficient, W/(m^2 K)
V	tank volume, m^3

Greek symbols

β	slope angle of collector, °
η_c	solar collector efficiency
ρ	density, kg/m^3
$(\tau\alpha)$	transmittance–absorbance product

Subscripts and superscripts

air	air
aux	auxiliary
col	solar collector
heat	heating
in	indoor
solar	solar energy
source	heat source
u	useful

Abbreviations

COP	Coefficient of Performance
FPC	Flat Plate Collector

sufficient solar energy potential with great specific heating demand and for this reason is the most suitable city for applying solar heating technologies.

In literature, numerous studies of solar assisted heat pumps systems are presented for heating and domestic hot water proposes [7–11]. Various energy tools have been used as ESP-r, Insel and EnergyPlus [12], but TRNSYS is used in the majority of studies [13–15]. Buker and Riffat [16], in a recent detailed literature review, stated that many parameters influence on the performance of solar assisted heat pump systems. Specifically, they concluded that many factors have influence on the system performance as the solar collector type, the refrigerant of heat pump, the environmental conditions, the system size and the load characteristics.

Studies that compare solar source heat pumps with other heating systems are very interesting. Sun et al. [17], compared a solar assisted heat pump heating system with an air source heat pump and concluded that the first performs better in all weather conditions. Especially in very cold climates Liu et al. [18] and Yang et al. [19] calculated the C.O.P. of a solar heat pump over 4, which is an impressive high value for so cold climates. It is important to say that the average C.O.P. of an air source heat pump is about 3 [20] and is lower than solar heat pumps in any case. The combination of solar and ambient sources together for driving heat pumps was investigated by many researchers. Chargui and Sammouda [21] used TRNSYS to simulate a residential house coupled with a dual source heat pump and concluded that a higher temperature of hot water improves the performance of the system and can give COP values greater than 6. Lerch et al. [22] compared a typical air source heat pump to an innovative solar source heat pump. The new system use directly the solar energy by using two evaporators in series and it consumes 30% less electricity than the typical air source system. Buker and Riffat [23] studied a novel solar thermal roof for heat pump operation and finally they found that this investment is feasible with a payback period of about 3 years.

Other studies compared solar heat pumps to ground heat pumps in order to predict which technology performs better. Busato et al. [24] made a comparison between ground and solar source heat pump systems with TRNSYS and they concluded that a multi-source system is the most ideal solution. The combination of these sources was investigated by Januševičius and Streckienė [25]. They examined a solar assisted ground source heat Pump system for a building with 180 m^2 and a low specific heating load of 18 kW h/m^2year with TRNSYS. They conclude that the C.O.P. of this system is over 4 for a collecting area of 7.4 m^2. Because the solar heat pump heating systems are much discussed technology, many optimizations on their operation have been published. Ahmad et al. [26] optimized the control system of a solar assisted heat pump in order to reduce the electricity cost. The final results proved that the on/off strategy is better than the linear multi-variable model. Qu et al. [27] compared the sensible and latent storage in a solar heat pump heating system and proved that the latent storage with phase change materials (PCM) increases the system efficiency about 50%.

In this work, a solar source heat pump system is compared to an air source heating system and to a simple solar driven fan coil system with auxiliary electrical heater. The comparison among these technologies is not usual in literature, so this study has an extra interest. More specifically, the comparison the solar assisted heat pump heating system is not only compared with the conventional air source heating system but also with another renewable heating system, something very interesting energetically and financially. Moreover, the comparison concerns a building of 100 m^2 in Athens where the three systems are compared energetically and financially in order to present a multilateral study. This Greek city combines high irradiation potential and has also high heating demand, two factors that make a suitable location for applying solar heating systems.

The main idea of this study is to compare an air source heat pump to a water source heat pump driven by solar collectors. The solar collectors increase the water temperature which is the heat source in the water source heat pump, making it to have greater performance. Moreover, a simple fan coil system driven by solar collectors coupled with an auxiliary electrical heater is analyzed in order to present a multilateral comparison. The three technologies are compared in energetic and financial terms, while the thermal comfort conditions are maintained in similar levels. In every case, the system optimization is made in January, the month with higher heating loads, a strategy that makes a safety design. Indoor temperature profiles are presented for all the winter period and for specific days in January with low temperature levels and low solar irradiation, the days that the solar heating systems face difficulties.