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Ground or solar source heat pump systems for space heating: Which is better? Energetic assessment based on a case history

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ABSTRACT

Outdoor air is a common heat source for heat pumps, whose limits are well known. However the use of different sources requires additional investment costs. It is then interesting, starting from a given additional investment, on one side to evaluate different compositions for a set of sources and on the other to choose the most favourable source from time to time, according to the building energy demand and the thermal level of each available source. This paper presents a study conducted on the base of a heating system based on multi-source heat pumps. By means of dynamic simulations in TRNSYS, several scenarios were assessed with respect to primary energy consumption in order to define, given an additional budget for the heat pump system, whether it is a good option to invest in ground source or in solar source for the heating systems.

The analysis reveals that the most energy efficient solution both for absorption and compression heat pump based systems is to adopt a multi-source system; the ground exchangers should then be sized to allow a minimum ground inlet temperature of −2 °C, and the saving in investment cost should be directed to buy solar collectors.

1. Introduction

The concept of low energy building is based on the reduction of the primary energy demand through a high insulation level, the use of high efficiency heating/cooling systems and the integration of renewable energy sources into the building plant. To reduce the heating installed capacity and the energy demand for the building heating, a good option is to start from the design of a low energy building with good thermal insulation and maximization of solar gains [1–3].

Concerning the use of high efficiency heating/cooling systems and the integration of renewable energy sources, the heat pump is one of the most advantageous systems to be considered in a HVAC plant. As it is well known, designing a heat pump system needs particular care concerning the selection of both the heating system (in order to lower heat supply temperature) and the heat source (external ambient air is the most diffused but the worst from thermodynamic point of view as the buildings heating loads generally increase as air temperature decreases) [4]. In particular, this second aspect should be carefully evaluated when designing a heat pump system as the potential advantages of alternative heat sources could be significant. This is why there is an increasing interest in dual source systems during the last decades both from the experimental and the theoretical point of view.

The main idea in dual source systems is that the heat pump absorbs heat by two heat sources. Two arrangements widely studied in literature are air source heat pump/solar collectors and ground source heat pump/solar collectors. The two typical configurations for the operation of such systems are "in series" (the two sources are aligned in series so that the former raises the temperature before that heat is taken from the latter) or "dual source" (the heat pump takes heat choosing time by time the most favourable source from the thermodynamic point of view) [5].

Rushenburg et al. [6] simulate a non-solar reference system and three solar-assisted heat pump systems providing domestic hot water and space heating for a single-family house in order to examine how much influence can be expected from ignoring or respecting the influence of direct evaporation or auxiliary energy, respectively.

Kaygusuz and Ayhan [7] did experimental investigations comparing a conventional solar system, a series heat pump system, a parallel heat pump system and a dual source heat pump system, obtaining the collector efficiency, heat pump coefficient of

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Nomenclature

Symbols

A	area (m^2)
ACHP	air compression heat pump
AEC	annual equivalent cost (€ y^{-1})
ASHP	air sorption heat pump
COP	coefficient of performance
E	primary energy (kWh)
EE	electrical energy
GC	specific ground exchangers cost (€ m^{-1})
GCHP	ground coupled compression heat pump
GHX	ground heat exchanger
GSHP	ground coupled sorption heat pump
GUE	gas use efficiency
HDD	heating degree days
HSPF	heating seasonal performance factor
HSGUE	heating seasonal gas use efficiency
L	length (m)
LHV	lower heating value
NG	natural gas
MARR	minimum attractive rate of return
PER	primary energy ratio
Q	thermal energy (kWh)
q	thermal power (kW)
SC	specific solar collectors cost (€ m^{-2})
TC	total cost (€)
W	electric energy (kWh)
w	electric power (kW)
η_{el}	electricity generation efficiency

Subscripts

a	absorber
abs	absorption
c	condenser
e	evaporator
el	electric
g	generator
gnd	ground
in	entering the system
out	leaving the system
sol	solar
th	thermal

performance, seasonal heating performance and the fraction of annual load met by free energy. An experimental study by Kaygusuz [5] was performed for a laboratory building in Trabzon, Turkey for space heating. The results indicate that the dual-source system is technically the most convenient solar heat-pump configuration, but before installing a solar-assisted heat-pump system a detailed economic analysis is needed.

The build-up and long-term performance test of a full-scale solar-assisted heat pump system for residential heating in Nordic climatic conditions were presented by Stojanovic and Akander [8].

Esen et al. [9] conducted performance experiments and economic analysis of a horizontal ground source heat pump system with a detailed cost analysis and payback periods when substituting for different local fuel/power sources. The same authors compared a ground-coupled with an air-coupled heat pump system from a techno-economic point of view evaluating the effects of parameters on the system performance [10]. To identify the conditions and possibilities of using solar heat in combination with ground-source heat pumps in single family dwellings was the main objective of the Kjellsson's study [11].

Esen studied the cylindrical phase change storage tank linked to a solar powered heat pump system both experimentally and theoretically [12]. More recently, Esen and Yuksel studied a hybrid system of ground source heat pump, solar collector and biogas designed and integrated to heat a greenhouse of 24 m^2 during the typical winter conditions in eastern Turkey [13]. A particular application of a ground source heat pump is described by Balbay and Esen to investigate the practicability of a system consisting of the vertical type single U-borehole heat exchangers with different lengths for snow melting on pavements and bridge decks; the study was conducted both experimentally and theoretically [14,15].

Nam et al. [16] developed a hybrid system that uses dual heat sources (groundwater and air source) and employs groundwater circulatory wells for long-term performance. Several case studies were conducted on the various conditions of introduction location, refrigerant and pumping rate, evaluating the coefficient of system performance also by real-scale experiments.

An experimental study of a solar-assisted ground-coupled heat pump system with solar seasonal thermal storage installed in a detached house was presented by Wang et al. [17]. In this case the results showed that the system could meet the heating and cooling energy needs of the building with an average coefficient of performance of the system of 6.55 and 21.35 respectively in heating and cooling mode (in the latter case the heat pump was not necessary to be started). Similar studies were conducted by Trillat-Berdal et al. [18] and by Chiasson and Yavuzturk [19].

All the studies presented refer to experimental or theoretical investigations of heat pumps systems with defined sizing characteristics and consider only marginally the economic point of view. The present paper deals with an example of good integration of the before mentioned three elements (building's high insulation, the use of heat pumps and the integration of renewable energy sources) into a real application, i.e. a new school building in Agordo, a mountain resort in Belluno province – North Italy. In this case a dual source (solar + ground) absorption heat pumps system was implemented. On the base of this real case study, several scenarios were assessed with respect to primary energy consumption by means of dynamic simulations in TRNSYS environment. The key issue of this paper is to determine if it is better to use solar assisted heat pumps or ground source heat pumps, or to integrate the two sources into a multi-source heat pump based heating system, to face the heating load of the building. This is done by both the energy and economic point of view, investigating also the sensitivity of the results of the analysis to the variation of a different heating load, different investment costs of the heat pumps' heat sources and cost of the energy sources.

2. Description of the building and HVAC plant

The detailed information about the climatic conditions, building composition, building energy load calculations and HVAC plants description is reported in previous works of the authors [20,21]. Here only the main data are briefly reported. The town of Agordo lies in the geographic area of the Dolomiti mountains (North-East of Italy) in a valley at 611 m a.s.l.; it has a temperate climate (Köppen climate classification Cfb–Cfc) with cold winters (3376 heating degree days – HDD[1]) and mild or cool summers, frequently associated with abundant rains. Monthly mean air temperatures are −2.9 °C and 18.3 °C in January and July respectively.

The main building features can be shortly indicated in 7150 m^2 of heated area with a volume of 32,000 m^3. The outdoor conditions

[1] Heating degree days are determined by subtracting the mean temperature for the day from the reference temperature (20 °C), then adding up those differences (when higher that 8 K) for the whole heating season [22].