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Influence of boundary conditions and component size on electricity demand in solar thermal and heat pump combisystems

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HIGHLIGHTS

- A simulation study on solar thermal and heat pump combisystem with two climates and buildings has been made.
- Penalty functions were used to ensure that all variations of the parametric study provided the same comfort requirements.
- Variation of heat pump size was shown to affect total system electricity use differently in the different climates and buildings.
- Heat pump losses (defrosting, start/stop, thermal) have significant impact on the annual electricity use, highlighting the importance of modelling these effects explicitly.

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ABSTRACT

Solar thermal and heat pump combisystems are used to produce domestic hot water (DHW) and space heating (SH) in dwellings. Many systems are available on the market. For an impartial comparison, a definite level of thermal comfort should be defined and ensured in all systems. This work studied the influence of component size on electricity demand for a state of the art solar thermal and heat pump system. A systematic series of parametric studies was carried out by using TRNSYS to show the impact of climate, load and size of main components as well as heat source for the heat pump. Penalty functions were used to ensure that all variations provided the same comfort requirements. Two reference systems were defined and modelled based on products on the market, one with ambient air and the other with borehole as heat source for the heat pump. The results show that changes in collector area from 5 to 15 m^2 result in a decrease in system electricity of between 305 and 552 kW h/year. Changes in heat exchanger size for DHW preparation were shown to give nearly as large changes in electricity use due to the fact that the set temperature in the store was changed to give the same thermal comfort in all cases. Decrease in heat pump size was shown to give a decrease in electricity use for the ASHP in the building with larger heat demand while it increased or had only a small change for other boundary conditions. Heat pump losses were shown to be an important factor highlighting the importance of modelling this factor explicitly.

1. Introduction

The use of solar thermal and heat pump combisystems is widespread in the market of space heating (SH) and hot water preparation (DHW) for single family houses. Recent studies of the state of art in Europe [1,2] have shown that solar collector can be used either in parallel or in series with heat pump. In parallel systems, both solar collector and heat pump provide heat for the loads either directly or via the store, while in series, heat from the solar collector is used indirectly as the heat source for a heat pump evaporator. Haller et al. [3] studied the use of solar heat for the evaporator and concluded that this was beneficial only when radiation on the collector was below certain threshold value, which was shown to be dependent on the efficiency of collector and heat pump as well as operating temperature levels.

Seasonal performance factor (SPF) of the whole system increases significantly when solar thermal is added in parallel with heat pumps, either air source (ASHP) or ground source (GSHP), because part of the heating demand is covered by the solar

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Nomenclature

ASHP	air source heat pump
AC45	ASHP, house with insulation standard SFH45 and with Carcassonne climate
AC100	ASHP, house with insulation standard SFH100 and with Carcassonne climate
AZ45	ASHP, house with insulation standard SFH45 and with Zurich climate
AZ100	ASHP, house with insulation standard SFH100 and Zurich climate
CA	Carcassonne
DHW	domestic hot water
FSC	fractional solar consumption
GSHP	ground source heat pump
GC45	GSHP, house with insulation standard SFH45 and with Carcassonne climate
GC100	GSHP, house with insulation standard SFH100 and with Carcassonne climate
GZ45	GSHP, house with insulation standard SFH45 and with Zurich climate
GZ100	GSHP, house with insulation standard SFH100 and Zurich climate
HP	heat pump
I	annual solar radiation (kW h/year)
$\dot{m}$	mass flow rate (kg/s)
p	pressure (Pa)
Q	annual thermal energy (kW h/year)
SFH	single family house
SH	space heating
SPF	seasonal performance factor
T	temperature (°C)
W	annual electrical energy consumption (kW h/year)
ZH	Zurich

Subscripts

Ctr	controller
cpr	compressor
DHW	domestic hot water
dist	circulation pumps
EH	auxiliary electrical heater
el	electrical
HP	heat pump
LOSS	losses
pen	penalties
S	south
SC	solar collector
SH	space heating
SHP	solar heat pump
Start/stop	heat pump start and stop
tot	total
V	system variation
45	tilt angle of solar collector

collectors. The ratio of heat delivered to electricity use is higher for solar collectors than for heat pumps. The increase in SPF is largely dependent on the heat load (total heat demand, share of DHW, and distribution over the year) as well as on the solar resource that is available (climate and collector area and orientation) [4].

The SPF of ASHP itself may not always be enhanced by adding solar thermal and this is shown in [5,6]. It was found that solar covered part of the thermal load during the time when the ASHP worked efficiently, i.e. spring and summer periods. Moreover, the system SPF was better in the solution with solar because the heat pump ran for a shorter time at high sink temperatures. In [6] results in terms of absolute electricity revealed higher savings for ASHP rather than for GSHP. This was due to the higher electricity use of the ASHP compared to the GSHP in the system used for comparison. Indeed, ASHP tend to use more electricity compared to GSHP and this for two main reasons. The first reason is that ASHP has a higher temperature difference between source and sink during the time of year when most of the heat is delivered. The second reason is that ASHP has larger losses than GSHP mostly for defrosting the ice that forms on the surface of the air heat exchanger (evaporator).

Research on solar combisystems is active and many studies are available in literature [7–30], with many including heat pumps as the auxiliary heat source. Colclough and McGrath in [7] presented a case study of a passive house with a solar thermal combisystem with a seasonal storage. Asaee et al. in [9] proposed a system configuration that is suitable for the heating and cooling of Canadian residential houses and the influence of climate, collector area and storage capacity on system performance was investigated. The solar field consisted of 24 m^2 flat plate collectors and served a 3 m^3 storage tank and a 0.2 m^3 pre-heated DHW tank. Results showed that the change in collector area had bigger impact than the change in storage size on annual solar fraction and for all climates investigated. Annual solar fraction ranged from 0.63 for 15 m^2 collector area and in Montreal to 0.86 for 36 m^2 in Edmonton. Kaçan et al. in [12,17] investigated small solar combisystems in Turkey. Collector area was 2.6 m^2 and the storage tank had a volume of 300 L. The auxiliary heat source was a 2 kW electrical heater placed in the storage tank. Energetic and exergetic efficiencies for each component and for the whole system were derived. One conclusion was that tank volume is an important parameter to use the gained energy effectively and avoid excessive energy production. Leconte in [18] used artificial neural network (ANN) for the characterisation of solar systems combined with boilers. A simulation model was verified by means of measurements under two different tests conditions. Experimental results showed small differences (lower than 2% in both tests) between measured data and numerical data in auxiliary energy use and in space heating energy. Much larger differences were shown for the captured solar energy due to that the model overestimated solar gains. Lundh et al. in [22] investigated the influence of the store geometry on the performance of the solar heating system and compared the performance of a storage tank with an internal auxiliary volume to the performance of a solution with an external unit. Maximum fractional savings were found at height to diameter ratios of 2–4 that includes the range recommended for commercial store. The comparison showed that a solution with an internal volume led to higher fractional energy savings for almost any volume and geometry configuration. Thür in [23] studied a solar combisystem combined with a condensing natural gas boiler. Simulations were carried out for the climate of Stockholm and for two system sizes, a small one (6 m^2 solar collector and a 300 L storage tank) and a large one (20 m^2 solar collector and a 1000 L storage tank) and results were compared to those of a traditional boiler system with no solar. Results showed larger energy savings for the large system. Spur et al. in [24] analysed the effects of common draw-off profiles on store performance and three realistic daily profiles, which were based on field measurements, were developed, concluding that it is important to have realistic DHW draw-off profiles for systems with internal heat exchangers for preparation of DHW. Jordan and Vajen [29] also found that realistic DHW profiles are important and derived a methodology to make synthetic but realistic profiles