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Research Paper

Performance analysis of a heat pump with desuperheater for residential buildings using different control and implementation strategies

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HIGHLIGHTS

- Performance analysis of an air-source heat pump with desuperheater for residential buildings was carried out.
- Different desuperheater control strategies and implementation were investigated.
- Seasonal performance factors and electrical energy savings used as performance figures.

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ABSTRACT

In this study, an extensive analysis of a desuperheater (DES) applied in a combined solar and air-source heat pump (ASHP) system for a residential low heating energy building (45 kW h/(m^2 a)) is carried out using the climatic conditions of Graz. The heat pump system uses R410A as refrigerant and has a heating capacity of 4.9 kW (@ A-12W35). The main focus of the investigation lies on the analysis of five different control strategies and types of integration of the DES into the system. For the investigations a validated TRNSYS heat pump model is implemented into a system simulation model, which comprises a buffer storage, a thermal solar collector and the heat distribution and heat dissipation system.

The results show energy saving potentials by applying a DES compared to the reference system without DES. This is mainly due to the lower amount of heat provided for "direct" domestic hot water (DHW) preparation by the heat pump. The results for the investigated control strategies show a maximum increase of the seasonal performance factor (SPF) and electrical energy savings of 5.3% and 5.0%, respectively, for an extra hydraulic loop of the DES with its own circulation pump. The other four strategies show annual electrical energy savings of about 4% compared to the reference system without DES.

1. Introduction

Heat pumps are widely used for domestic hot water (DHW) preparation and space heating (SH) and offer the possibility to substitute conventional heating systems (direct electric, oil boiler, gas boiler, etc.) and to reduce the primary energy consumption [1].

Especially air-source heat pumps (ASHP) are widely used in residential heating and cooling systems due to their low installation costs and their effectiveness [2]. The European heat pump market shows that air-to-water heat pumps play an important role, reflected in their large market share [3]. The Austrian heat pump market has also developed toward an increase of air-to-water heat pumps in the recent decade [4].

Concerning the increasing market share of ASHPs it is of interest to increase the performance of this technology. One possibility is to implement a desuperheater (DES), which is an additional small heat exchanger that is installed directly after the compressor and before the actual condenser of the heat pump. The DES transfers the heat of the superheated refrigerant vapor to a secondary circuit, which is connected to a thermal energy storage (TES) system, where the energy can be stored and then used for DHW (directly or indirectly). The condensation of the de-superheated refrigerant takes place in the condenser of the heat pump, which usually transfers heat to the heating system or to a buffer storage tank. Hence heat pump operation with a DES usually means a simultaneous preparation of heating water for space heating with a moderate temperature (30–35 °C in case of a floor heating system) and DHW with a relatively high temperature of 50–60 °C. The advantage of this simultaneous operation is that the heat pump operates at a lower high-side pressure compared to DHW preparation only.

Experimental investigations concerning the thermal performance of a DES for DHW preparation analyzing the effect of different water and refrigerant inlet temperatures have been performed

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Nomenclature

ASHP	air-source heat pump
BUI	building
c	specific heat capacity
Cdot	capacity flow ($\dot{m} \cdot c_p$) in W/K
COP	coefficient of performance
DHW	domestic hot water
DES	desuperheater
f	factor
GSHP	ground-source heat pump
HP	heat pump
$\dot{m}$	mass flow rate kg/h
Mfr	mass flow rate in kg/h
P	power in kW
$\dot{Q}$	heating capacity in kW
Q	energy in kW h
REF	reference system (without DES)
RIP	relative inlet position
ROP	relative outlet position
SC	solar collector loop
SH	space heating
SPF	seasonal performance factor
T	temperature in K
TES	thermal energy storage
ΔT	temperature difference in K
var	variable
W	work in kJ or kW h or MW h

Greek symbols

τ	time in s
λ	thermal conductivity in W/(mK)
π	pressure ratio

Subscripts

amb	ambient
comp	compressor
cond	condenser
ctr	control devices
DHW	domestic hot water
DES	desuperheater
el	electric
hp	heat pump or high pressure
in	inlet
OUT	outlet
pen	penalty
pu	circulation pump
ref/r	refrigerant
sc	solar collector loop
set	set point
SH	space heating
sub	diff. between discharge temperature and DES water outlet temperature
sys	system
th	thermal Energy in kW h_{th}
w	water

by Lee and Jones [5] and they used the data to validate an analytical model [6]. Shao et al. [7] have done a simulation study using a desuperheater and a preheater for DHW for different modes of heating and cooling operation in an air-to-water system. They are reporting energy savings of 31%, which are achieved compared to a system using direct electrical water heating.

A ground-source heat pump system (water-to-water) used for heating and cooling, equipped with a desuperheater for DHW preparation was investigated by Cui et al. [8] by means of simulations. The system was compared to a conventional ground-coupled heat pump system, also using an electric heater for preparing DHW. However, nearly 95% of the DHW demand can be covered by the desuperheater system. Biaou and Bernier [9] have studied four systems for preparing DHW, including a ground-source heat pump with a desuperheater. Also here a direct comparison between DHW preparation by a heat pump with and without desuperheater was not performed.

The natural refrigerant ammonia in a low capacity heat pump system with DES has been investigated by Palm [10] by means of laboratory tests. The results within this study show high COP values. However, some problems concerning the lack of available components for ammonia, like a hermetic compressor for ammonia and problems due to poor lubrication are also reported.

A validated GSHP heat pump model with DES has been developed by Blanco et al. [11]. The authors used the COP as key parameter for the evaluations and stated that the highest COP for space heating (SH) mode and combined SH and DHW preparation occur at different superheating degrees. An analysis of the annual performance of a heat pump system with desuperheater was not performed. In [12] the same authors have done experimental investigations on a monovalent inverter-driven water-to-water heat pump. Three modes (SH heating only, DHW preparation only and combined mode) have been examined, where the coefficient of performance was used as key parameter. An analysis of the annual performance and a comparison to a system without desuperheater was not performed. In [13] the same authors have performed investigations of the seasonal performance of a monovalent inverter-driven water-to-water heat pump with a desuperheater by means of simulations. However, the focus of this study was on control schemes for different electricity tariff plans in order to minimize costs.

Among the more recent work is Safa et al. [14]. Here a field test study in two buildings has been carried out under the climatic conditions of Ontario. The obtained and extrapolated measured results indicate a potential to increase the system efficiency by implementing a DES in GSHPs. Also recent research work on hybrid renewable microgeneration system for multiple residential and small office buildings by means of TRNSYS simulations has been done by Entchev et al. [15]. Within this study three cases were investigated where a conventional system (boiler) was used as reference case and compared to two GSHP systems (with and without photovoltaic thermal collector) including a DES for DHW. The results show high potential to save overall energy by applying renewable systems including DES for DHW in multiple residential and small office buildings. Within this study the DES is implemented in the overall renewable system but not analyzed in detail.

Liu et al. [16] have done an experimental study of a multifunctional water source heat pump system with desuperheater, where in the heating mode, hot water is produced by two-step heating (two heat exchangers, DES and condenser). Results are based on experiments and an analysis of the seasonal performance is not reported.

A system, in which the heat pump condenser and desuperheater are integrated into a storage tank, was presented by Heinz et al. [17]. A simulation model for the system has been developed and validated with experimental data. An analysis of the seasonal performance of the system was not yet reported.