Energy and Buildings 156 (2017) 197–206

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Air source integrated heat pump simulation model for EnergyPlus☆

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ARTICLE INFO

Article history:
Received 22 June 2017
Received in revised form
21 September 2017
Accepted 23 September 2017
Available online 28 September 2017

Keywords:
Integrated heat pump
Building energy modeling
Grid Integration

ABSTRACT

Air source integrated heat pump (ASIHP) is an air source, multi-functional space-conditioning unit with water heating function (WH), which can lead to significant energy savings by recovering condensing waste heat in the cooling season and providing dedicated or desuperheating heat pump water heating in the remaining months. This paper summarizes development of the EnergyPlus ASIHP model. It introduces the physics, sub-models, working modes, and control logic. Based on the model, building energy simulations were conducted to demonstrate greater than 50% annual energy savings, in comparison to a baseline heat pump with electric water heater, over 10 US cities, using the EnergyPlus quick-service restaurant template building. We assessed water heating energy saving potentials using ASIHP versus gas heating, and identified the climate zones where ASIHPs are promising. In addition, a grid integration strategy was investigated to reveal further energy saving and electricity cost reduction potentials, via increasing the water heating set-point temperature during off-peak hours and using larger water tanks.

Published by Elsevier B.V.

1. Introduction

An Air Source Integrated Heat Pump (ASIHP) is an air source, multi-functional space-conditioning unit with water heating function (WH), as shown in Fig. 1, which generally uses a variable-speed compressor, indoor blower, and outdoor fan. It has an outdoor unit and indoor air handler with air-to-refrigerant heat exchangers (R-A HX) just as a typical heat pump unit. The addition is a water heater, using a double-walled tube-in-tube or brazed heat exchanger (R-W HX) to heat water in a storage tank. Some ASIHP products may circulate the hot water in a water-to-air heat exchanger (W-A HX) downstream of the indoor R-A HX to temper the indoor supply air during an enhanced dehumidification mode. By recovering the condenser waste heat for water heating and by providing dedicated heat pump water heating capability, ASIHPs are able to achieve significant energy savings. While the waste heat recovery is not free due to the elevated condensing temperatures required to meet domestic hot water needs in full condensing WH operation, the combined mode is quite efficient as both space cooling and full condensing water heating are delivered from one compressor power input.

Murphy et al. conducted sub-hourly annual energy use simulations to compare the performance of the ASIHP system concept to that of a baseline suite of individual systems; 3.8 W/W Cooling Season Performance Factor (CSPF) [13.0 Btu/Wh Seasonal Energy Efficiency Ratio (SEER)] heat pump with humidifier option, 0.90 W/W energy factor (EF) electric WH, a standalone space dehumidifier of 1.4 EF. The TRNSYS 16 (Klein [10]) system simulation software platform was used to conduct these analyses for five US locations – representing cold (Chicago), mixed humid (Atlanta), hot humid (Houston), hot dry (Phoenix), and marine (San Francisco) climate zones. A tight, very well insulated house was used for the analyses. Results of these analyses showed that the estimated annual energy savings for the initial ASIHP concept prototype design ranged from about 46% in Chicago to almost 70% in San Francisco. In addition, estimated summer afternoon peak demand for the ASIHP ranged from 20% to ∼60% lower than that of the baseline system depending on location.

Abbreviations: ASIHP, air source integrated heat pump; COP, coefficient of performance; DOE, U.S. Department of Energy; DWH, dedicated water heating; HVAC, heating, ventilating, and air-conditioning; IDF, EnergyPlus input data file; SC, space cooling; SCDWH, space cooling and water heating with desuperheating; SCWH, space cooling and water heating; SH, space heating; SHDWH, space heating and water heating with desuperheating; WH, water heating (function).

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https://doi.org/10.1016/j.enbuild.2017.09.064
0378-7788/Published by Elsevier B.V.

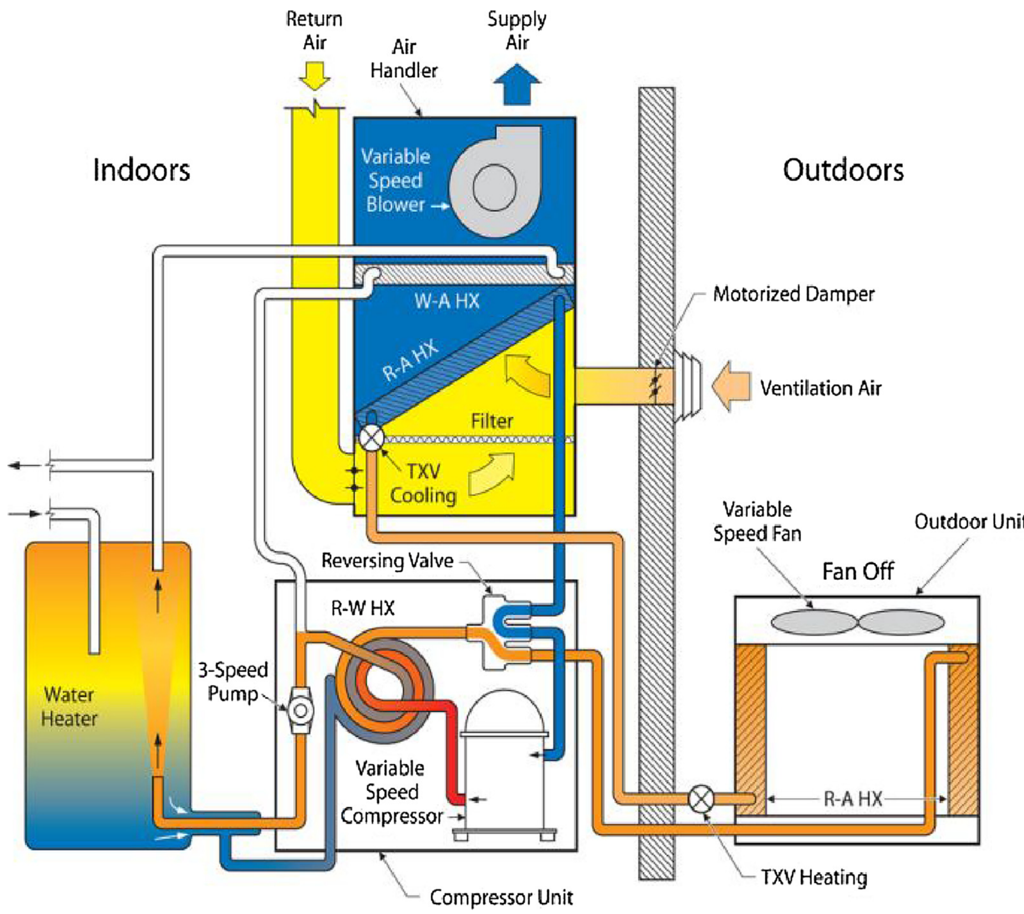

Fig. 1. Schematic of air source integrated heat pump.

Rice et al. [12] introduced development of a residential ASIHP in partnership with a U.S. manufacturer. A nominal 10.6 kW (3-ton) cooling capacity variable-speed unit, the system provides both space conditioning and water heating. This multifunctional unit can provide domestic water heating in either full condensing (dedicated water heating or simultaneous space cooling and water heating) or desuperheating operation modes. Laboratory test data were used to calibrate a vapor compression simulation model for each mode of operation. The model was used to optimize the internal control options for efficiency while maintaining acceptable comfort conditions and refrigerant-side pressures and temperatures within allowable compressor operating envelopes. Annual simulations were performed with the ASIHP installed in a well-insulated house in five U.S. climate zones, using TRNSYS 16. The system was predicted to use 45–60% less energy than a DOE minimum efficiency baseline system while meeting total annual space conditioning and water heating loads.

The energy saving of an integrated heat pump is mainly due to heat recovery using condenser heat for water heating. Heinz et al. [7] developed a numerical model for a heat pump condenser and desuperheater integrated to a water storage tank. The model was used to conduct both design calculations of the condenser/desuperheater and annual simulations of the system integrated into a whole heating system. The water tank model is a one-dimensional stratified model. The authors compared laboratory measurements with codenser/desuperheater and water tank temperatures. Hengel and Heinz [8] performed extensive analyses for in a combined solar and air-source heat pump system for a residential building having low heating load. They investigated numerous control strategies for the desuperheater using a TRNSYS heat pump model coupled with a buffer storage tank, a thermal solar collector and the heat distribution and heat dissipation system. The TRNSYS (Klein) [10] building energy simulation predicted around 4% energy saving, in comparison to a baseline heat pump. Justin et al. [9] used TRNSYS to simulate an integrated solar heat pump using an ice slurry tank for latent energy storage. They conducted annual energy simulations in four Canadian climate zones and revealed 17%–28% energy savings, compared to a baseline air-to-water heat pump. Claudia and Enzo [3] modelled a multi-functional heat pump with condenser heat recovery for water heating. The energy saving by the heat recovery in cooling season was reported up to 30%. Fucci et al. [6] studied a heat pump for heat recovery in a ventilation system, to use the exhaust air as the source and use the condenser heat to warm up the ventilation air. They conducted experiments via varying outdoor air temperature from −5 to 10 °C and controlling the indoor air at 20 °C. The measured overall system COP reached 9.5. The literature search indicates that studies on a full-version of multi-functional ASIHP are still lacking, i.e. a unit capable of all the space heating, space cooling and water heating modes. In particular, a freely available building energy simulation tool, which is able to reveal ASIHPs' energy saving potentials in various climate zones, needs to be developed.

The U.S. Department of Energy (DOE) has invested in developing such an advanced, cutting-edge technology for years and now it is ready to be launched to the market. Due to premium variable-speed compressors and fans applied, the initial cost of an ASIHP is rather high. However, the payback period should be acceptable due to its significant energy saving potential, i.e., >50%. EnergyPlus [4] is a building energy modeling tool developed and maintained