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Research Paper

Simulation-based optimization of heating and cooling seasonal performances of an air-to-air heat pump considering operating and design parameters using genetic algorithm

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HIGHLIGHT

- A simulation model is developed to optimize seasonal performance of a heat pump.
- Genetic algorithm is used to optimize operating and design parameters.
- Considered design parameters are peak load and compressor volume.
- Improvement of SCOP and SEER based on the optimization is analyzed.

ARTICLE INFO

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SCOP
Neural network
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ABSTRACT

In this study, a novel simulation model is developed to optimize the seasonal coefficient of performance (SCOP) and seasonal energy efficiency ratio (SEER) of air-to-air heat pumps under various operating and design parameters. The developed heat exchanger model is simplified using artificial neural networks. The operating and design parameters were optimized to maximize the SEER and SCOP according to the outdoor temperature using the genetic algorithm. The considered operating and design parameters included the compressor frequency, indoor air flow rate, outdoor air flow rate, peak load, and compressor volume. The SCOP and SEER with the optimization of all three operating parameters were 7.0% and 21.4% higher than those with the optimization of the compressor frequency, respectively. In addition, the maximum designed cooling peak load, which satisfied the SEER greater than 8.5, was 3.7 kW. Moreover, the maximum SCOP was observed at the designed heating peak load of 3.8 kW. Further, as the compressor volume increases by 37.2% and 22.8% over the baseline compressor volume, the SCOP and SEER increase by 3.8% and 1.1%, respectively.

1. Introduction

Owing to growing climate change concerns, extensive studies have been conducted to reduce the environmental impacts of heat pumps. Previous indicators for the environmental impacts were limited to the characteristics of refrigerants, such as the ozone depletion potential and global warming potential. However, in recent years, the use of a comprehensive indicator for greenhouse gas emissions and energy consumption has been recommended [1]. To attenuate the environmental impacts, both the minimization of greenhouse gas emissions and the maximization of the energy efficiency of heat pumps are required. Grignon-Masse et al. [2] analyzed policy strategies to assess the environmental impacts of room air conditioners. Barreira et al. [3] investigated the relationship between energy efficiency enhancement and production cost reduction in residential air conditioners. Li [4] stressed the importance of the energy efficiency enhancement of a packaged air conditioner using R-410A because the energy consumption accounted for more than 70% of the total carbon dioxide equivalent emissions based on the life cycle climate performance. To reduce the energy consumption, the optimal energy efficiency of the heat pumps needs to be obtained not only under the standard condition but also under various part load conditions.

Various simulation studies have been conducted to estimate the seasonal performance of heat pumps. Kinab et al. [5] calculated the seasonal coefficient of performance (SCOP) and seasonal energy efficiency ratio (SEER) of a heat pump using a simulation tool. Simplified simulation models for air conditioners were also developed to optimize the operating parameters using the performance data provided by the

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Nomenclature

A	area (mm^2)
C	heat capacity ($J\,K^{-1}$)
C_d	degradation coefficient
COP	coefficient of performance
CR_u	capacity ratio
D	displacement (mm^2)
EER	energy efficiency ratio
elbu	power consumption of electric backup heater (kW)
F	compressor frequency (Hz)
G	mass flux ($kg\,s^{-1}\,m^{-2}$)
h	heat transfer coefficient ($W\,m^{-2}\,K^{-1}$)
i	enthalpy ($kJ\,kg^{-1}$)
ID	indoor
k	conductivity ($W\,m^{-1}\,K^{-1}$)
L	thermal load (kW), length (m)
$\dot{m}$	mass flow rate ($kg\,h^{-1}$)
NTU	number of transfer units
n	bin hour (h),
OD	outdoor
P	pressure (MPa)
P_n	number of motor winding poles
Q	heat transfer rate (kW)
R	resistance
r	radius (mm)
SCOP	seasonal coefficient of performance
SEER	seasonal energy efficiency ratio
T	temperature (°C)
U	overall heat transfer coefficient ($W\,m^{-2}\,K^{-1}$)
$\dot{V}$	volumetric flow rate ($m^3\,min^{-1}$)
W	power consumption (kW)

Greek letters

ε	effectiveness
η	efficiency
ρ	density ($kg\,m^{-3}$)

Subscripts

a	air
act	actual
c	cooling
CND	condenser
comp	compressor
EVP	evaporator
h	heating
i	in
j	bin number
IDU	indoor unit
isen	isentropic
max	maximum
min	minimum
o	out
ODU	outdoor unit
r	refrigerant
sh	superheat
vol	volumetric

manufacturers [6–8]. Bourke and Bansal [9] showed that the performance of a heat pump water heater was reduced by 12% using the simplified water use requirement. Bagarella et al. [10] evaluated how the heat pump and thermal storage sizing influence the seasonal performance. Madonna and Bazzocchi [11] reported that the seasonal performance of heat pumps improved by up to 25% by optimizing the ratio of the cooling peak load to the heating peak load. Naldi et al. [12] analyzed the effects of the bivalent temperature and thermal storage volume on the seasonal performance of air-to-water heat pumps. Palmiter et al. [13] and Kim and Braun [14] evaluated the effects of the refrigerant charge on the seasonal performance of heat pumps. Ribeiro and Barbosa [15] estimated the effects of the oil circulation ratio on the SEER of an air conditioner. They reported that the SEER of the air conditioner decreased with an increase in the oil circulation ratio. In et al. [16] measured the SCOP and SEER of a residential heat pump using low global warming potential refrigerants. They reported that both the SCOP and SEER of the R-32 heat pump increased by 8% with a 20% decrease in the refrigerant charge.

As stated previously, the effects of the operating and design parameters on the seasonal performance of air conditioners and heat pumps have been investigated extensively. However, many studies evaluated the seasonal performance of the heat pumps based on the coefficient of performance (COP) or the energy efficiency ratio (EER) under the standard condition [11,16]. Even though simplified simulation models for air conditioners were developed to optimize the operating parameters, the optimization of the design parameters for maximizing the seasonal performance under the part load conditions has rarely been conducted. Moreover, studies on the optimal design of the compressor under the part load conditions are very limited, even though it is very important to improve the seasonal performance of the heat pumps.

The aim of this study is to improve the SCOP and SEER of air-to-air heat pumps by optimizing the operating and design parameters in a short time. A novel simulation model was developed to optimize the SCOP and SEER of the air-to-air heat pumps under various operating and design parameters. For rapid calculations, the heat exchanger model was simplified using artificial neural networks. Based on the heat pump simulation model, the heating and cooling performance characteristics of the air-to-air heat pump were estimated under the part load conditions. Moreover, the operating parameters were optimized to maximize the SCOP and SEER according to the outdoor temperature, using the genetic algorithm. The considered operating parameters included the compressor frequency, indoor air flow rate, and outdoor air flow rate. In addition, based on the optimized operating parameters, the effects of the design parameters on the SCOP and SEER were analyzed under various load conditions. The considered design parameters contained the peak load and compressor volume.

2. Experiments

Fig. 1 shows the schematic of the experimental setup for measuring the heating (or cooling) performance of an R-410A heat pump under various operating conditions. The heat pump consisted of a hermetic twin rotary compressor, an electronic expansion valve, and two fin-tube heat exchangers. The displacement volume of the twin rotary compressor was approximately 19 cm^3 rev^{-1}. The optimum refrigerant charge was determined to be 1000 g, for yielding the maximum EER under the standard conditions [16]. A corrugated fin-tube heat exchanger with a heat transfer area of 20.5 m^2 was used for the condenser in the outdoor unit, and a slit fin-tube heat exchanger with a heat transfer area of 6.4 m^2 was used for the evaporator in the indoor unit. The detailed specifications of the heat exchangers are presented in Table 1.

The power consumption of the compressor and fans was measured using a power meter, with an accuracy of ± 0.2%. The refrigerant flow rate at the condenser outlet was measured using a Coriolis-effect mass flowmeter, with an accuracy of ± 0.1%. Digital pressure transducers