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A comprehensive approach to find the performance map of a heat pump using experiment and soft computing methods

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ABSTRACT

A novel systematic practical approach to simulate the performance of heat pumps precisely is presented. In the proposed method, by conducting a number of experiments as well using soft computing techniques, the operation of all of the components is modeled comprehensively. The application of the method is examined for an experimental setup. The effective adjustable parameters are selected in a way that enabled them to be changed freely in the experimental setup. The Mean absolute error of prediction of coefficient of performance for validation measured experimental data is only 2.95%. In addition, to provide a comprehensive insight, an extensive sensitivity analysis considering nine performance parameters, such as mass flow rate of refrigerant and pressure drop of condenser, is conducted. It is found that the minimum possible is the best value of inlet temperature of water of condenser. Moreover, for inlet temperature of water of evaporator, frequency of compressor and degree of superheating which are the other adjustable effective parameters trade-offs among performance parameters are observed. For example, increasing the degree of superheating led to improve required work and isentropic efficiency of compressor as well as coefficient of performance and pressure drop of condenser, while it decreased the delivered heat.

1. Introduction

During recent years, fossil fuels have been consumed more and more. The rate of consumption has been much faster than rate of production. As a result, these resources are being depleted. This concern as well as growing related environmental issues lead to increase in demand for efficient energy technologies [1]. Heat pumps have been progressively acquiring importance due to the energetic and economic advantages of provision of heating requirements in industry, trades and households [2].

In heat pumps, a large part of the required thermal energy is provided free of charge from the environment, for example, it can be obtained from air [3], groundwater and surface water [4], or the ground [5]. The required energy may also be taken from another heat pump at a lower temperature. Due to their consumption of electrical energy, heat pumps lift the level of energy. After that, the energy is transferred to a system that is going to be heated [6]. By using heat pumps to heat buildings, almost 75% of the required energy is extracted from the environment, and the remaining 25% is obtained through electrical energy [7]. As a result, a heat pump is a system with immense potential of saving energy and reducing greenhouse emissions compared to other conventional heating systems, such as oil or gas heaters [7]. Heat pumps are extensively and increasingly utilized in European and Western countries [8].

During recent years, there have been several different studies in the field of heat pumps. For instance, Sivasakthivel et al. [8] conducted an experimental study to evaluate the performance of a ground source heat pump. The experimental data showed that the average values of the effectiveness of the ground source heat exchanger were 0.29 and 0.33 in the operation at heating and cooling modes, respectively [8]. In another study, Minglu et al. [9] experimented a cascade air source heat pump water heater to acquire the best controlling strategy. Their experimental results demonstrated that having a controller for refrigerant at the intermediate pressure as well as electronic expansion valves had a great impact on the system performance. Huang et al. [10] proposed a novel heat recovery device designed for re-use of the energy of the compressor shell. The obtained experimental data indicated that the compressor's suction temperature rose from 295.45 K to 320.55 K and the specific isentropic work decreased by 23.4%, which were very significant. Using an experimental setup, Fannou et al. [11] analyzed a ground sourced heat pump in heating mode. The measurements showed that the value of COP varied between 2.70 and 3.44, which gave an

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Nomenclature

a_n	output of transform function of neuron
bias	bias of neuron
c	coefficient of stepwise regression method
COP	coefficient of performance (–)
d	coefficient of stepwise regression method
ESU	estimated standard uncertainty
f	correction factor
frequency	frequency (Hz)
h	enthalpy ($kJ\cdot kg^{-1}$)
h'	function of enthalpy of saturated liquid of water ($kJ\cdot kg^{-1}$)
in	input of neuron
$\dot{m}$	fluid mass flow rate ($kg\cdot s^{-1}$)
MAE	mean absolute error
max pow	maximum power
n	number of effective parameters
net	input of transform function of neuron
num_{data}	number of data
P	pressure (kPa)
pureline	linear function
$\dot{Q}$	thermal power (kW)
R^2	coefficient of determination
RDP	ratio of condenser to evaporator pressure drops
r_P	pressure ratio (–)
r_T	temperature ratio (–)
s	entropy ($kJ\cdot kg^{-1}\cdot K^{-1}$)
SD	standard deviation
T	temperature (K)
tansig	hyperbolic tangent sigmoid function
$\dot{V}$	volumetric flow ($m^3\cdot s^{-1}$)
W	weight of neuron
$\dot{W}$	electrical power (W)
x	input
Y	actual (observed) value
$\overline{Y}$	average of Actual (observed) values
$\hat{Y}$	predicted value
Y_0	constant value of stepwise regression method
z	coefficient of stepwise regression method
Z_3	dimensionless enthalpy ratio of condenser

Abbreviations

ANN	artificial neural network
ANFIS	adaptive neuro-fuzzy interface system
SCST	soft computing and statistical tools
SRM	stepwise regression method
NIST	national institute of standards and technology
REFPROP	reference fluid thermodynamic and transport properties

Scripts

atm	atmosphere
cat	catalogue
comp	compressor
cond	condenser
cor	corrected
cr	critical
dhe	dimensionless heat gain of expansion valve
dim	dimensionless
evap	evaporator
exv	expansion valve
f	saturated liquid
g	saturated vapor
ie	isentropic efficiency
is	isentropic
max pow	maximum power
mfr	mass flow rate
L	layer in neural network
ref	refrigerant
sat-liq	saturated liquid
SPH	super heating
w	water

Greek symbols

Δ	difference
η	efficiency (–)

average value of 2.87. Moreover, the comparative study implied that the application of heat pump, instead of electricity in order to provide heating in cold seasons, led to saving almost 70% in electricity consumption.

The studies mentioned above were investigations done only experimentally. Although conducting experiments gives a beneficial point of view from the operation of systems, it cannot bring a comprehensive insight individually. This means that it is not possible to estimate the performance of the system under different operational conditions using just the reported experimental data. Therefore, another group of studies tried to simulate the operation of a heat pump. These kind of studies are either totally theoretical or a combination of experimental and theoretical approaches. In these studies, the simplified relations, commercial software programs, or soft computing methods such as artificial neural network (ANN) have been used to simulate the operation of heat pumps.

Sayyaadi et al. [12] improved the performance of a vertical ground source heat pump considering different scenarios. They utilized a single-optimization thermodynamic, a single-optimization economic and a multi-objective thermo economic, and compared the obtained results. It was a completely theoretical study in which the simplified relations were employed in order to simulate the performance of the system. According to the results, increase in operating hours as well as the price of electricity led to increase in the total product cost of multi-objective optimization. Furthermore, it gradually made the corresponding values of the thermo economic and single-objective optimization closer together.

A ground source heat pump was modeled and tested by Montagud et al. [13] in official application. Modelling of the ground source heat pump was done using GLHEPRO software program and the results of the simulation were validated with experimental data. Annual operation of the heat pump was also simulated by TRNSYS and a similar validation process was conducted. They obtained the values of pressure and temperature in each time interval.

Sun et al. [14] employed ANN and adaptive neuro-fuzzy interface system (ANFIS) in order to predict the coefficient of performance of two ground source heat pumps. The monitored experimental data was used to develop the models. The results showed that the obtained models had a high accuracy in comparison to the other methods. Arat and Arsalan [15] also found the best artificial neural network to predict COP and exergetic efficiency of a heat pump. They examined different layers of neurons as well as four training algorithms to acquire the most accurate one. Same as the study of Sun et al. [14], it was found that soft computing and statistical tools (SCST) gave precise estimations. Moreover, Mathioulakis et al. [16] found an easy-to-implement artificial neural network in order to estimate the electrical work by delivering heat power and COP of an air to water heat pump. In this study, only two effective parameters, namely input temperatures of the evaporator and