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The evaluation of operation performance of HVAC system based on the ideal operation level of system

Xing Fang, Xinqiao Jin*, Zhimin Du, Yijun Wang

School of Mechanical Engineering, Shanghai Jiao Tong University, Shanghai 200240, PR China

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ABSTRACT

This paper presents an evaluation method of operation performance of a HVAC system based on the ideal operation level of system. The HVAC system is divided into three subsystems and the ideal exergy flow model of each subsystem is set up based on exergy analysis. The ideal operation level of subsystem is defined and obtained by minimizing avoidable part of exergy destruction caused by the control condition. Based on the ideal operation levels of three HVAC subsystems, the ideal operation level of the HVAC system is set up. The evaluation index-improvement potential (IP_{sys}) is defined to evaluate the operation performance of the HVAC system based on the ideal operation level. Five control strategies are applied in the HVAC system to validate the evaluation index and the evaluation method. The results show that the daily IP_{sys} of using the global optimization control strategy on a typical day is 0.115 and is the smallest among those five strategies. It implies that the operation performance of the HVAC system with the global optimization control strategy is the closest to the idea operation level. The evaluation results indicate that the evaluation method not only can evaluate the operation performance of the HVAC system, but also can give the direction for improving the operation performance of the HVAC system.

1. Introduction

Heating, ventilation and air conditioning (HVAC) system is a complicated energy system which includes many subsystems and equipments. The operation performance of HVAC system depends on its equipments' efficiencies, operation conditions and control strategies. To evaluate the operation performance of a HVAC system, total energy efficiency is used as the evaluation index commonly, which based on the first law of thermodynamics. However, the first law of thermodynamics cannot describe the thermodynamic efficiency and loss of system. Exergy, based on the second law of thermodynamic, represents the "work potential" of energy. It is a powerful tool for the design, analysis, and optimization of thermal systems [1]. In recent years, it is reported that exergy analysis method has been used to analyze the operation performance of thermal system [2,3].

Hepbasli and Akdemir [4] presented an exergy analysis method for ground source heat pumps (GSHP), using exergy diagram to describe the exergy loss of different system components. The results showed that the highest irreversibility occurred in the motor–compressor, and the total magnitude of the losses was over 56% of the actual power input. Sakulpipatsin et al. [5] applied exergy analysis in a building and the HVAC system, discussed the exergy efficiency of building and HVAC system in both cooling and heating cases. The exergy analysis pinpointed that the thermal energy emission, the control system and the energy conversion system were the main causes of the exergy inefficiencies in the heating and cooling cases, respectively. Ahamed et al. [6] applied exergy analysis in a vapor compression refrigeration system, and showed that the maximum exergy loss occurred in the compressor among all components. Results also showed that for better performance of the system, compressor discharge and suction temperature should be within 65 °C and 14 °C, respectively. Yildiz and Gungor [7] performed energy and exergy analysis for the whole process of space heating in the buildings. The results showed that the highest efficiency values in terms of energy and exergy were found to be 80.9% for external air-air heat pump and 8.69% for LNG condensing boiler, respectively. Wei and Zmeureanu [8] utilized energy and exergy analysis for evaluating two types of VAV systems operating in a large office building in Montreal. Through the analysis, it was found that the largest improvement of the exergy efficiency of the system could be obtained by changing the heating source, from electricity to renewable energy sources such as solar or geothermal. Balta et al. [9] employed energy and exergy analysis to assess the performances of four heating options (heat pump,

* Corresponding author at: Institute of Refrigeration and Cryogenics, Shanghai Jiao Tong University, Shanghai, PR China.
E-mail address: xqjin@sjtu.edu.cn (X. Jin).

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Nomenclature

E	exergy (kW)
I	exergy destruction (kW)
F	exergy fuel (kW)
P	exergy product (kW)
χ	exergy destruction ratio (%)
η	exergy efficiency (%)
k	unit exergy consumption
h	specific enthalpy (kJ/kg)
s	specific entropy (kJ/kg K)
ψ	specific exergy (kJ/kg)
Q	cooling load (kW)
W	power consumption (kW)
M	mass flow rate (kg/s)
COP	coefficient of performance
PLR	part load ratio
$c_{p,w}$	specific heat capacity of water (kJ/kg K)
$c_{p,a}$	specific heat capacity of dry air (kJ/kg K)
$c_{p,v}$	specific heat capacity of vapor air (kJ/kg K)
p	pressure (Pa)
ω	humidity ratio (kg/kg(dry air))
R	gas constant
IP	improvement potential

Subscripts and superscripts

CT	cooling tower
CH	chiller
CHP	chilled water pump
CDP	cooling water pump
$SCHP$	secondary pump
AHU	air handling unit
I	subsystem I
II	subsystem II
III	subsystem III
0	dead state
in	inlet
out	outlet
r	refrigerant
ev	evaporator
cd	condenser
com	compressor
exp	expansion valve
$cycle$	vapor compression refrigeration cycle
ht	heat transfer
chw	chilled water
cdw	cooling water
cta	air in cooling tower
$AHUa$	air in AHU
ave	average
cap	capacity
nom	nominal
$recv$	correction
min	minimum
max	maximum
a	air
sub	subsystem
sys	system
$ideal$	ideal operation condition
$actual$	actual operation condition
set	set-point
db	dry bulb
wb	wet bulb

condensing boiler, conventional boiler and solar heating system) for a building by energy and exergy efficiencies and sustainability index. The results showed that overall exergy efficiencies of heat pump, condensing boiler, conventional boiler and solar heating systems were 3.66%, 3.31%, 2.91%, and 12.64%, while the sustainability index values for the four cases considered were 1.039, 1.034, 1.030 and 1.144. Solar collector system had the highest energetic and exergetic renewability. Ghosh and Dincer [10] presented energy and exergy assessments of a new integrated system with different psychrometric processes for HVAC&R applications. The mass, energy, entropy and exergy balance equations for all system components and processes were developed for analysis and performance assessment purposes. Results showed the energy and exergy efficiencies of the integrated system were calculated to be 18.6% and 33.31%, respectively, which were normally less than 10% for specific processes through the conventional systems.

Commonly, in exergy analysis, indexes such as exergy destruction, exergy efficiency, etc., are applied to evaluate the operation performance of various HVAC systems. However, those indexes cannot represent directly the potential of a system that can be improved. For the total exergy destruction of a system, it can be divided into two parts, one is the avoidable part caused by the control condition, and the other part is the unavoidable part caused by the irreversible processes in system, such as friction, heat loss, unrestrained expansion, etc. [11]. In order to evaluate the improvement potential of a system, it is important to ascertain the avoidable part of exergy destruction caused by the control condition. Recently, many researchers have applied an advanced exergy analysis [12] to analyze the composition of the exergy destruction for various energy systems. Such analysis facilitates the understanding of the improvement potential of energy systems.

Mosaffa and Park [13] applied advanced exergy analysis in an air conditioning system consisting of a combination of LHTS (latent heat thermal storage) and VCR (vapor compression refrigeration). The analysis was performed by splitting the exergy destruction into unavoidable and avoidable parts. The results of splitting the exergy destruction rate showed that for the real process of system, 0.283 kW of the exergy destruction rate (13.23% of overall exergy destruction rate) was unavoidable and 0.799 kW (37.58% of overall exergy destruction rate) was due only to the irreversibilities within the components themselves. Cziesla et al. [14] performed advanced exergy analysis in an externally fired combined cycle (EFCC), calculated avoidable and unavoidable exergy destruction for each component. The results showed that the effect of design improvements in the bottoming cycle on the overall exergetic efficiency was less than in the gas turbine section including the combustion chamber. Tan and Kecebas [15] used advanced exergy-based methods to identify the potential for improvement of the operation performance of a geothermal district heating system (GDHS), and the potential for energy savings in terms of thermodynamic and economic aspects. The results showed that improvement potential and the total cost-savings potential of the overall system were determined to be 2.98% and 14.05%, respectively. Keçebas and Gokgedik [16] carried out both conventional and advanced exergy analyses of an existing geothermal binary power system. The results of the advanced analysis were found to be more qualified than the results of the conventional one. The total system efficiency under actual conditions was 9.60%, and this efficiency could be improved to 18.26% through maximum developments. Vuckovic et al. [17] used the advanced exergy analysis to identify the performance critical components and the potential for exergy efficiency improvement of a complex industrial energy supply plant. The results showed that the highest exergy destruction was caused by the steam boiler, and 83.53% of the total exergy destruction in the steam boiler could not be avoided.