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Research Paper

A comparative thermodynamic analysis of air handling units at variable reference temperature

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HIGHLIGHTS

- Exergy analysis using coenthalpies at variable reference temperature has been used.
- COP, universal and functional exergy efficiencies of four AHUs are calculated.
- Using heat exchanger of higher effectiveness the efficiency can be improved.
- Using advanced HP control the performance of AHU can be improved considerably.
- Functional exergy efficiency is more informative than universal exergy efficiency.

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ABSTRACT

Ventilation and air conditioning systems are emerging as the major energy consumers in low energy buildings. The objective of this paper is to present new methodology for assessment of Air Handling Units (AHUs) taking into account the variations of reference temperature. The methodology using the concept of coenthalpy, developed for heat exchangers and published by the authors previously has been used. Four AHUs that comprise energy transfer devices, such as: Water-to-Air Heater (WAH), Heat Recovery Exchanger (HRE) and Heat Pump (HP) have been investigated. Thermodynamic parameters including Coefficient of Performance (COP), universal and functional exergy efficiencies have been used to compare AHUs and to calculate the exergy destruction in AHU components at variable environment temperature $-30\,^{\circ}\mathrm{C}\ldots+10\,^{\circ}\mathrm{C}$. The results of this study show that using HRE the COP and exergy efficiencies are significantly better compared with AHU without HRE. Using the HRE of higher effectiveness, the thermodynamic indicators can be improved considerably. The study shows that AHUs equipped with HP with advanced control method and HRE are more advantageous compared with other investigated AHUs.

The presented methodology could have practical application for evaluating of energy and exergy efficiency of AHUs at different reference temperatures when designing HVAC systems and implementing optimum control methods.

1. Introduction

In recent decades, due to stricter energy efficiency requirements the thermal performance of buildings has been rapidly improving. Due to increased thermal insulation of building envelope the heat demand for space heating reduces [1]. Therefore, in modern low energy buildings the major energy consumers are ventilation and air conditioning systems that are designed to provide air of suitable quality [2,3]. To save thermal energy in airtight and well insulated buildings the ventilation systems with heat recovery units are often recommended. Therefore, improvement of those systems is of vital importance in order to achieve better indoor climate and to reduce energy consumption in buildings [4,5].

To investigate Heating Ventilation and Air Conditioning (HVAC) systems, which can consist of different subsystems, a variety of methods can be used. One of those methods is thermodynamic or exergy analysis. Using this method, the quality of energy could be evaluated [6–8]. Exergy is a useful quantity that stems from the combination of the second and first laws of thermodynamics. The exergy of a system is defined as the maximum shaft work that can be done by the system at a

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Nomenclature

Abbreviations

AHU	air handling unit
CM	compressor
CN	condenser
COP	coefficient of performance
EV	evaporator
Fe	exhaust fan
Fs	supply fan
HP	heat pump
HRE	heat recovery exchanger
HVAC	heating, ventilation, and air conditioning
TV	throttle valve
WAH	water-to-air heat exchanger

Variables

c_p	specific heat capacity, kJ/kg K
e	specific exergy, kJ/kg
$e^{\pm}$	specific external exergy crossing system boundaries, kJ/kg
$\dot{E}$	exergy flow rate, kW
h	specific enthalpy, kJ/kg
k	specific coenthalpy, kJ/kg
l	specific destroyed exergy, kJ/kg
$\dot{M}$	mass flow rate, kg/s
s	specific entropy, kJ/kg K
T	temperature, °C
q	specific thermal energy, kJ/kg
$\dot{Q}$	heat transfer flow rate, kW
ε_T	effectiveness of heat recovery exchanger, dimensionless
η_F	functional exergy efficiency, dimensionless
η_U	universal exergy efficiency, dimensionless

Subscripts

a	air
AHU	air handling unit
c	state of cold air
CM	compressor
CN	condenser
consum	consumed
e	state of outside air (reference environment)
E	state of exhaust air temperature after AHU
EV	evaporator
Fe	exhaust fan
Fs	supply fan
h	state of hot air after the exhaust fan (Fig. 3)
HRE	heat recovery exchanger
i	state of fluid
in	incoming
K	state of air after condenser or other air heater (Fig. 3)
out	outgoing
prod	produced
R	Room
refr	refrigerant
V	ventilation
w	state of warm air after heat recovery exchanger (Fig. 3)
W	water
WAH	Water-to-air heat exchanger
Win	water inlet
Wout	water outlet
1, 2, 3, 4, 5	heat pump cycle states

Superscripts

+	to the system (supplied to the system)
–	out of the system (leaving the system)

specified reference environment [9,10]. The thermodynamic reference environment (temperature or pressure) “acts as an infinite system, and is a sink and source for heat and materials” [11]. When exergy analysis is used it is important to follow universal principles of the method that could be applied for system components or whole systems. Therefore, the choice of reference environment, which can be constant, variable or averaged over the chosen period is a very important step. For example, in an important study on low exergy buildings it “is recommended to use the (current) surrounding outdoor air as the reference environment for the exergy analysis of buildings and their energy supply systems” [12]. However, there is no recommendation in this study how to conduct the exergy analysis when the reference temperature is variable.

HVAC systems are the systems where the temperatures of the working fluids are close to the environment temperatures. However, there is no strict agreement among researchers what reference temperature should be used when conducting exergy analysis of those systems. Some researchers recommend using the reference (dead) state temperature, which is based on the daily or monthly average temperature [13] or on the average annual temperature of particular location [14]. Others perform studies based on seasonal temperatures [3,15,16]. Torío et al. [17] has conducted research on the selection of the reference temperature for the exergy analysis. Their review study shows that when the properties of a system are close to those of the reference environment, results from the exergy analysis undergo strong variations depending on the definition of the reference environment chosen. Therefore, when analysing HVAC systems it is extremely important to choose appropriate reference temperature. It is worth mentioning that, as noticed by Laverge and Janssens, “the use of average temperatures to calculate the Carnot efficiency therefore introduces an error” [18]. This is not always taken into account when conducting exergy analysis of HVAC systems.

The exergy analysis can be used to analyse the whole system or to investigate separate subsystems or system components. One of the objectives of the exergy analysis is to improve the efficiency of energy conversion systems and to identify components where the exergy destruction occurs. Also, an optimisation of energy conversion processes could be performed using the exergy parameters as indicators. The operation of energy conversion systems depends on the efficiency of separate components and subsystems, operating conditions and control strategies [6].

There are many studies on the exergy analysis of HVAC systems and components. The exergy analysis of air conditioning and refrigeration systems were presented by Dincer and Rosen [9], where the effect of the reference temperature on the results of exergy analysis was shown. Review studies on application of exergy analysis were published by Torío et al., Hepbasli, Park et al., [17,19,20]. The exergy analysis of building energy systems using the low exergy principle was presented in [12,21,22]. The exergy analysis of heat exchangers for HVAC systems was conducted by Martinaitis and Streckiene [23], and dehumidification and other processes were analysed in [24,25].

Chengqin et al. [26] evaluated four evaporative cooling systems at two ambient temperature conditions (+33 °C and +36 °C). Their results showed that the effectiveness of the heat exchanger of the indirect evaporative cooling system was important in improving the exergy efficiency of the regenerative system.

Wei and Zmeureanu [15] presented the exergy analysis of variable air volume systems for air-conditioning. Two thermodynamic indicators: Coefficient of Performance (COP) and exergy efficiency were