Energy and Buildings 128 (2016) 876–885

Contents lists available at ScienceDirect

Energy and Buildings

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

Exergy and entransy analyses in air-conditioning system part 1—Similarity and distinction

Tao Zhang[a,b], Xiaohua Liu[a,*], Haida Tang[a], Jun Liu[a], Yi Jiang[a]

[a] Department of Building Science, Tsinghua University, Beijing 100084, China
[b] School of Aerospace, Tsinghua University, Beijing 100084, China

ARTICLE INFO

Article history:
Received 24 April 2016
Received in revised form 20 July 2016
Accepted 25 July 2016
Available online 26 July 2016

Keyword:
Thermological analysis
Exergy destruction
Entransy dissipation
Performance optimization
Air-conditioning system

ABSTRACT

Thermological analysis is supposed to be an effective approach for performance optimization of an air-conditioning system. Exergy and entransy are two common thermological parameters taking the influences of both heating/cooling capacity Q and temperature grade T into account. In the present study, similarities and distinctions between exergy and entransy analyses are investigated. Exergy destruction and entransy dissipation for mixing process and heat transfer process are investigated, which could be expressed in $(1-T_0/T)-Q$ diagram and $T-Q$ diagram respectively. Formulas of exergy destruction and entransy dissipation are deduced. Exergy and entransy analyses tend to be in accordance with each other in the common temperature range of the air-conditioning system. To identify the leading reasons restricting performance, exergy destruction or entransy dissipation can be divided into two parts: one that is limited heat transfer ability and the other arises from the unmatched properties (embodied in an unmatched coefficient ξ higher than 1). It's helpful to improve performance of the air-conditioning system through reducing exergy destruction or entransy dissipation. It's concluded to choose different theoretical parameters in terms of different purposes: entransy is more appropriate for a transfer process while exergy is more recommended for the heat-work conversion process. The present analysis is beneficial to choose an appropriate theoretical tool for performance optimization in the air-conditioning system.

1. Introduction

Nowadays building energy consumption is still increasing with the development of economy and society, accounting for about 20% of the total energy consumption in China [1]. The air-conditioning system including heating and cooling usually consumes about 30%–60% [1,2] of the total building energy. It's of great importance to improve the energy efficiency of the air-conditioning system and reduce its energy consumption in buildings. Then how to improve the performance of an air-conditioning system becomes a key issue both for researches and applications. Continuous efforts have been paid in proposing appropriate approaches for performance optimization of an air-conditioning system [3,4]. Conventional method usually focuses on the heating/cooling capacity Q and performance optimization could be carried out through pure calculation or simulation. However this method could not provide a clear understanding on the essence of the air-conditioning system. Thermal analysis in terms of thermodynamic parameters are treated as a theoretical approach for performance optimization in the air-conditioning system [5]. The thermal analysis method is to identify the losses existing in the system and try to find approaches for performance optimization through reducing losses.

Exergy or entropy analysis is a common thermodynamic tool adopted in the air-conditioning system. There have been plenty of exergy analyses on heat transfer process, refrigeration or heat pump cycle, coupled heat and mass transfer processes and so on [6–10]. Exergy destruction and exergy efficiency are commonly utilized as the indexes reflecting the thermodynamic performance of a certain handling process or the entire system. Shukuya [6] studied how to describe a built environment control system such as space heating and cooling by exergy. Through the perspective of exergy, an air-source heat pump is basically a device to separate exergy supplied by electricity into warm or cool exergies. Manjunath et al. [8] provided a state-of-the-art review of second law of thermodynamic analysis of heat exchangers. Performance parameters in terms of entropy generation, exergy analysis and manufacturing irreversibilities were mentioned, highlighting the importance of the second law of thermodynamics leading to energy conservation.

---

[*] Corresponding author.
E-mail address: lxh@mail.tsinghua.edu.cn (X. Liu).

http://dx.doi.org/10.1016/j.enbuild.2016.07.055
0378-7788/

Nomenclature

A	Heat or mass transfer area (m^2)
c_p	Specific heat capacity (kJ/kg °C)
E_n	Entransy (kW K)
E_x	Exergy (kW)
ΔE_n	Entransy dissipation (kW K)
m	Mass flow rate (kg/s)
Q	Cooling capacity (kW)
R	Equivalent thermal resistance (K/W)
T	Absolute temperature (K)
t	Temperature (°C)
U	Heat transfer coefficient (kW/m^2 °C)
W	Power consumption (kW)

Greek symbols

ξ	Unmatched coefficient (dimensionless)
η	Thermodynamic perfectness (dimensionless)

Subscripts

ac	Air-conditioning system
CH	Chiller (mechanical refrigeration cycle)
c	Low temperature fluid
cond	Condenser
des	Exergy destruction
dis	Entransy dissipation
evap	Evaporator
h	High temperature fluid
in	Inlet state
m	Mass transfer process
out	Outlet state

An exergetic optimal controller for a vapor compression system was designed by Jain et al. [9]. Simulation results showed that this exergy-based model minimizing exergy destruction achieved over 40% greater exergetic efficiency during operation. Hurdogan et al. [10] dealed with the performance analysis and evaluation of a novel desiccant cooling system using exergy analysis method. The exergy destructions in each of the components were determined in terms of the experimental results. The exergetic efficiency values were also calculated to depict the thermal performance, which varied from round 10%–32%.

Exergy analysis has also been adopted in investigating the performance of the entire HVAC systems in buildings [11–16]. In the IEA EBC Annexes 37 and 49 [11,12], exergy is chosen as a theoretical tool for constructing low-exergy buildings, which present significant benefits in improving energy efficiency. Fan et al. [13] focused on an airport terminal's HVAC system and investigated its performance with indexes such as the unit exergy cost, the object exergy efficiency and the exergy loss ratio. Razmara et al. [14] presented an exergy model for a building and proposed an exergy-based control technique to improve the performance of the HVAC system. Simulation results showed that the novel method achieved a 4% reduction in exergy destruction as well as saving 12% more energy. Sakulpipatsin et al. [15] investigated the performance of a low- temperature heating and high temperature cooling system in the Netherlands. With detailed discussions on thermal energy and thermal exergy losses, leading approaches for increasing the exergy efficiency are proposed.

On the other hand, entransy is a thermological parameter that was introduced to analyze the heat transfer process [17]. Rapid progress has been achieved in adopting entransy analysis in optimizing different heat transfer processes in the recent 10 years [18–21]. Equivalent heat resistance on the basis of entransy dissipation is used to optimize the heat transfer process, in which achieving the lowest equivalent heat resistance under certain constraints is the most important goal. Çarpinlioğlu [21] investigated the performance of a desiccant wheel cooling system using both exergy destruction (as well as entropy generation) and entransy dissipation. The similarity between the application of entransy and exergy was discussed. Variances of exergetic efficiency and entransy dissipation were in accordance with the *COP* of the desiccant wheel system. In the Annex 59 project [22], entransy is chosen as a theoretical tool to evaluate and optimize the performance of the air-conditioning system.

Table 1
Temperature differences in the typical air-conditioning system shown in Fig. 1.

Components	ΔT	Input of the system	
		Heat or mass transfer capacity	Energy consumption
FCU	ΔT_1		W_{FCU}
	ΔT_2	Transfer area of FCU	W_{CWP}
	ΔT_3	Transfer area of evaporator	
Outdoor air processor	ΔT_{1a}		W_{FAN}
	ΔT_{2a}	Transfer area of cooling coil	W_{CWP}
	ΔT_3	Transfer area of evaporator	
Condensing side	ΔT_4	Transfer area of condenser	
	ΔT_5		W_{CTP}
	ΔT_6	Transfer area of cooling tower	W_{CT}
Chiller	ΔT_{CH}		W_{CH}

However there are seldom studies on the comparison between exergy analysis and entransy analysis in the air-conditioning system. Present research will focus on the similarities and distinctions between exergy and entransy analyses. Choosing typical handling processes as examples, exergy destruction and entransy dissipation will be investigated. It's expected that the present analysis will be helpful for choosing an appropriate theoretical tool for performance optimization in the air-conditioning system.

2. Typical handling processes in HVAC systems

2.1. Temperature levels of typical handling processes

Schematic of the FCUs (Fan Coil Units) and outdoor air system is illustrated in Fig. 1 chosen as an example to investigate the temperature levels of the air-conditioning system. A chiller produces 7 °C chilled water, and the chilled water is supplied to the FCUs and the outdoor air handling units to remove both the sensible load and the moisture load of the building. The condensing heat is then released into the atmosphere through the cooling tower. As indicated by the standards of mechanical chillers in different countries [23–25], rated supply temperature of chilled water is about 7 °C. The leading reason is that condensation dehumidification is adopted for removing indoor moisture load. The required cooling source temperature for dehumidification is indoor dew point temperature in theory.

Fig. 2 presents the temperature level of each component in the handling process and the main temperature differences existing in this air-conditioning system are listed in Table 1. The temperature difference between the outdoor wet bulb temperature (cooling tower is adopted) and the indoor air temperature is only 2 K. However, the temperature difference between the condensing and evaporating sides ($\Delta T_{CH} = T_{cond} - T_{evap}$) is as high as 32 K. The larger the temperature difference of the chiller, the lower its COP_{CH} and the greater the power input (W_{CH}) required for the same cooling capacity Q_{CH}, as calculated by Eq. (1).

$$W_{CH} = \frac{Q_{CH}}{COP_{CH}} = \frac{Q_{CH}}{\eta \cdot T_{evap}} \left(T_{cond} - T_{evap} \right) \tag{1}$$