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Exergy analysis of two humidification process methods in air-conditioning systems

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ABSTRACT

Exergy analysis is a technique for systems and processes that can be used to evaluate the distribution of availability losses in a system, so that measures and priorities with improvement potential can be developed. This article investigates the difference between the amount of exergy consumption and exergy loss (irreversibility) in the two methods of humidification, namely Constant Enthalpy Humidification (CEH) and Constant Temperature Humidification (CTH) in a Heating Ventilation and Air Conditioning (HVAC) system. In this work a 15 × 9 × 3 m room with a 10000 cfm Air Handling Unit (AHU), and a 30 and 25 m of supply-and-return duct (30–25, respectively) are considered to investigate the exergy consumptions and irreversibilities of the components in the two humidification methods. The results show that the summation of irreversibilities in CEH is less than the CTH. In addition the power input of CEH in design condition is 12% less than the CTH, mostly due to large exergy consumption of the steam preparation in the humidification process. It can be concluded that CEH has superiority over the CTH due to less exergy consumption in the HVAC systems.

1. Introduction

Energy is a major element in the development of economy and in the improvement of the quality of human life. Energy consumed in the HVAC system accounts for approximately 20% of the total energy consumption, and nowadays, the effective use of energy is deemed important [1].

Exergy is a useful concept since it constitutes the link between the physical world, the engineering world and the surrounding environment, and it determined the true efficiency level of engineering systems, thus considered as a useful concept to make improvements; therefore, exergy is used in the design of engineering systems and in relation with energy and exergy utilization [2]. Unlike energy, exergy is conserved only during ideal conditions and destroyed due to irreversibility in real conditions [3].

The use of the above concept may become more important when the concept of exergy efficiency is related to the sustainable development of buildings. Although today there is no standard method for calculating the sustainability of buildings, the use of exergy analysis may reveal some information about the inefficient use of natural resources and where, in a thermal system, the change may have maximum effect [4]. In this relation, Nishikawa and Shukaya [5] studied the impact of exergy stored in the building mass on the exergy destruction by heating and cooling systems. Franconi and Brandemuehl [6] compared the exergy performance of two types of air conditioning systems, namely the constant air volume (CAV) systems and the variable air volume (VAV) systems. They discovered that exergy balance shows the advantage of VAV system over CAV by reducing the exergy depleted in cooling coils, reheat coils and fans.

Bejan [7] introduces a method of exergy analysis when the process or system undergoes a control volume psychometric process. It is noted that total exergy is determined as the sum of thermomechanical exergy and chemical exergy, where the latter is the major component of total exergy, which involves a mixture of different elements such as moist air at different temperatures and compositions [8].

Some articles have presented the exergy analysis of HVAC systems, mostly for small residential buildings. Wepfer et al. [9], for example, calculated the exergy of different fluids commonly encountered in HVAC application and showed the exergy analysis of some chosen psychometric processes such as mixing and dehumidification. Also, Yumrutas et al. [10] found the effect of evaporation and condensation temperatures on the second law efficiency and Coefficient of Performance (COP) of the cycle. And Alpuche et al. [11] analyzed a packaged single-zone

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Nomenclature

R_v	Water vapor gas constant (kJ kg^{-1} K^{-1})
R_a	Dry air gas constant (kJ kg^{-1} K^{-1})
$C_{p,v}$	Vapor specific heat at constant pressure (kJ kg^{-1} K^{-1})
$C_{p,a}$	Dry air specific heat at cons. pressure (kJ kg^{-1} K^{-1})
E	Exergy (kJ)
e	Specific exergy (kJ kg^{-1})
h	Specific enthalpy (kJ kg^{-1})
$\dot{m}_a$	Mass flow rate of dry air (kg s^{-1})
$\dot{m}_v$	Mass flow rate of water vapor (kg s^{-1})
$\dot{m}_w$	Mass flow rate of water (kg s^{-1})
m	Mass of a substance (kg)
t	Time (s)
T_0	Dead state temperature (°C)
P_0	Dead state pressure (kPa)
ω	Specific humidity (g kg^{-1})
ω_{in}	Inlet specific humidity (g kg^{-1})
ω_{out}	Outlet specific humidity (g kg^{-1})
i	Specific irreversibility (kJ kg^{-1})
N_i	Number mole of species
ε	Mole fraction of vapor
y_ν	Mole fraction of vapor
y_a	Mole fraction of air
$\bar{\omega}$	Mole fraction ratio
μ_i	Chemical potential (kJ kmol^{-1})
P	Pressure (kPa)
S	Entropy (kJ K^{-1})
s	Specific entropy (kJ kg^{-1} K^{-1})
Q	Heat transfer (kJ)
T	Temperature (°C)
w	Specific work (kJ kg^{-1})
ϕ	Relative humidity (%)
$T_{C_{in}}$	Water inlet temperature (°C)
$T_{C_{out}}$	Water outlet temperature (°C)
$P_{C_{in}}$	Water inlet pressure (kPa)
$P_{C_{out}}$	Water outlet pressure (kPa)
T_{in}	Air inlet temperature (°C)
T_{out}	Air outlet temperature (°C)
P_{in}	Air inlet pressure (kPa)
P_{out}	Air outlet pressure (kPa)

Abbreviation

H.W.S	Hot water supply
H.W.R	Hot water return
C.W.S	Cold water supply
C.W.R	Cold water return
P1	Humidification pump
P2	Hot water circulation pump
P3	Cold water circulation pump
F.A	Fresh air
R.A	Return air
S.A	Supply air
M.B	Mixing box
L.C.C	Leaving cooling coil
L.H.C	Leaving heating coil
I.H	Inlet humidification
L.H	Leaving humidification
L.F	Leaving fan
CTH	Constant temperature humidification
CEH	Constant enthalpy humidification
S.H.F	Sensible heat factor
Irr.	Irreversibility
AHU	Air handling unit
C.O.P	Coefficient of performance

Subscripts

ph.	Physical or thermo mechanical
gen.	Generation
Ch.	Chemical
Hum.	Humidification
tot.	Total
act.	Actual
des.	Destroy
sat.	Saturation
amb.	Ambient
C.V	Control volume
ke	Kinetic energy
pe	Potential energy
ν	Water vapor
0	Ambient dead state
00	Properties of the environment
a	Air or inlet to humidification
b	Outlet from humidification
c	Saturation condition
w	Wet bulb temperature or water
f	Saturated liquid, fluid
ν	Saturated vapor, gas
i	Species
in	Inlet
out	Outlet
d	Dry bulb
T	Properties in temperature T

air-conditioning unit with a dehumidifier, and found that its annual exergy efficiency was 1.8–6.3%.

To name more, Shukuya and Hammache [12] provided a comprehensive description of exergy analysis and some examples of evaporative cooling systems and space heating systems, but they did not mention that in some cases the dehumidification process is vital or that a variable reference state needs to be considered when it is relatively close to the interior condition of a building. Sakulpipatsin et al. [13] presented an extended method for exergy analysis of buildings and Heating Ventilation Air Conditioning (HVAC) systems, according to an energy demand build-up model from the building side to the energy supply side. The HVAC systems comprise a thermal energy emission and control system, a thermal distribution system, an electricity distribution system and an energy conversion system. They found that thermal exergy and thermal energy demands of the building and thermal energy and thermal exergy losses occurring in the HVAC systems are discussed.

Caliskan et al. [14] presented energy and exergy analyses and sustainability assessment of one novel and three conventional types of air cooling systems for building applications. They found that at the dead state temperatures of higher than 23 °C (comfort temperature), exergy efficiency and sustainability of the novel system, which is based on the novel Maisotsenko cycle (M-Cycle), is higher than those of the conventional systems. Also at a dead state temperature of 50 °C, novel cooling system's exergy efficiency can reach 60.329% as the maximum, while the minimum exergy efficiency of other conventional cooling systems becomes as low as 35.866%, respectively.

In Fenghua et al. [15] study thermal comfort index PMV analyses, energy and exergy analyses for air cooling process in buildings