Energy & Buildings 172 (2018) 478–492

Contents lists available at ScienceDirect

Energy & Buildings

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

Performance analysis and evaluation of desiccant air-handling unit under various operation condition through measurement and simulation in hot and humid climate

Makiko Ukai[a,*], Hiroaki Tanaka[b], Hideki Tanaka[c], Masaya Okumiya[a]

[a] Nagoya University, Graduate School of Environmental Studies, Nagoya, Japan
[b] Nikken Sekkei LTD, Tokyo, Japan
[c] Nagoya University, Campus Planning & Environment Management Office, Nagoya, Japan

ARTICLE INFO

Article history:
Received 13 July 2017
Revised 6 March 2018
Accepted 18 April 2018
Available online 8 May 2018

Keywords:
Desiccant air handling unit
Measurement analysis
Performance evaluation
System simulation

ABSTRACT

In hot and humid climate such as in Japan and south east Asia, dehumidification in summer is really important for air conditioning. Temperature and humidity independent control (THIC) of air conditioning system can handle sensible heat and latent heat separately, and provide good indoor environment and achieve energy conservation. Desiccant air handling unit is one of the major solution for THIC of air conditioning system. It needs hot water to regenerate sorbent which absorbs moist in the air. Combined heat and power can supply hot water at almost constant temperature for desiccant air handling system and also contribute to the business continuity plan of commercial buildings. However, there are still uncertainties about the factors which affect energy performance of desiccant air handling unit and the optimum design and operations in hot and humid climate. The objectives of this paper are to prove factors which affect energy performance of desiccant air handling unit by measurement analysis and show optimum condition of the desiccant air handling unit under various room conditions by simulation. Measurement analysis shows that energy performance of desiccant air handling unit depends not only on the inlet air condition to dehumidification wheel but also on designed supply air humidity. Furthermore, simulation results show the optimum inlet air condition entering dehumidification wheel under various supply air absolute humidity which is determined by design room conditions. These results provide useful information of desiccant air handling unit during design and operation phase of buildings in hot and humid climate.

1. Introduction

In April 2014, the first strategic energy plan [1] after the Great East Japan Earthquake was approved in a cabinet meeting. As more than half of the final energy consumption corresponds to thermal use, it is important to use heat efficiently. In terms of the energy balance between primary energy demand and final energy consumption in Japan [2], the energy loss caused by power generation and distribution is around 36%, therefore, it is necessary to promote onsite combined heat and power system (hereafter CHP) and renewable energy system. In addition, after the disaster in 2011, in terms of energy security in a building itself, the installation of CHPs has been increasing [3].

CHP is a system the main purpose of which is to generate electricity. When generating electricity, some energy is discarded as waste heat, but for CHP, the waste heat is recovered as steam or hot water. The efficiency of electric power generation is 15–50% and overall efficiency is 60–85% with micro turbine [4]. When waste heat is used efficiently, the total efficiency of CHP is higher than that of the power plant for the grid.

Efficient use of heat from CHP and renewable thermal energy is really challenging because there is not much hot water load especially in office buildings during summer. The representative ways for use of heat in summer are [5]:

- heat is provided to generator as heat source of absorption chiller in order to release the refrigerant as a vapor;
- heat is provided to adsorption chiller in order to regenerate the adsorbent;
- heat is provided to regenerating coil in order to regenerate dehumidifier which contains moisture in a desiccant air handling unit (DAHU) for latent heat process.

* Corresponding author.
E-mail address: ukai@davinci.nuac.nagoya-u.ac.jp (M. Ukai).

https://doi.org/10.1016/j.enbuild.2018.04.040
0378-7788/© 2018 Published by Elsevier B.V.

Nomenclature

ABS-G	double-effect absorption chiller
ABS-GH	gas-fired double effect with hot water single effect absorption chiller
CHP	combined heat and power
C	specific heat [kJ/kgK]
COP	coefficient of performance [-]
DAHU	desiccant air handling unit
H	Enthalpy [kJ/kg]
HVAC	Heating, ventilation and air conditioning
LHV	lower heating value
Q	coil demand [kJ/h]
RH	relative humidity [%]
SAHU	Sensible heat air handling unit
SCOP	system coefficient of performance
SEC	sensible exchange coefficient [-]
T	temperature [°C]
THI-AHU	temperature and humidity independent control of air handling unit
V	air volume [m^3/h]
W	face velocity [m/s]
X	absolute humidity [kg/kg']
ρ	density [kg/m^3]
η	coefficient of relative humidity [-]
k, l, m, n, o, p, q, r, s, t, u, v	constant value

Subscript

a	air
after	after cooling coil
by	by product view point
CHP	combined heat and power
des	desiccant
main	main product view point
pro	process side
pre	pre-cooling coil
pre_w_i	inlet water to pre-cooling coil
ra	return air
re	regenerating coil
dw	dehumidification wheel
sa	supply air
14 °C	chilled water temperature at 14 °C
7 °C	chilled water temperature at 7 °C

An absorption cycle is a heat-activated thermal cycle. The great advantage of this type of cycle is that any source of heat can be used including low-temperature source such as waste heat. When installing an absorption chiller with only waste heat as heat source, it is normally a single-effect absorption chiller and its typical nominal COP is around 0.7 [6]. To overcome the performance limitation, double-effect absorption chillers with separate generator for high temperature and low temperature have been developed since the 1980s [7]. In case that thermal energy is not enough for the demand, as back-up function, a combustor in an absorption chiller can burn natural gas. In addition, COP of triple-effect absorption chillers has been improved around 1.74. With the technology development, even the low temperature at 75 °C of hot water can be applied as a heat source for the generator [8].

Adsorption chiller can soak up a large quantity of refrigerant vapor at relatively low temperature [5]. However, the disadvantage of installing adsorption chiller is the limitation of COP. According to the experimental results conducted by Wang [9], COP is achieved 0.43 with 16.5 °C chilled water and 84.4 °C hot water.

DAHU has been developed as temperature and humidity independent control of air conditioning unit (THI-AHU). The advantages of installing THI–AHU are follows [10,11]:

- sensible and latent heat can be controlled separately;
- set point for chilled water temperature of chiller can be raised and it results in higher COP of chiller;
- reheating process air is not necessary;
- air quality is better because condensation is avoided in the unit.

DAHU removes moisture in air using adsorbent or sorbent. Adsorbent such as silica gel has lower adsorption capacity and requires higher regeneration temperature. There is a lot of research on performance analysis and evaluation with silica gel.

Rang et al. [12] conducted mathematical modeled simulation with the heat and mass transfer process of dehumidification wheel coated with silica gel. The results provide preferable conductivity value of the substrate and the optimal rotation speed to obtain the lowest processed outlet absolute humidity. However, energy performance of DAHU was not provided.

Giovanni et al. [13] conducted experimental analysis with DAHU driven by a micro CHP in terms of primary energy saving. In this experiment, silica gel is also used. DAHU with a micro CHP is compared to the conventional system with cooling dehumidification and reheating of the supply air. Results show primary energy saving for DAHU with a micro CHP achieves maximum 9% compared to the conventional system. However, in this facility, energy saving effect depending on chilled water temperature is not investigated.

As new adsorbent, polymer sorbent has been developed and achieves greater dehumidification with low regeneration temperature around 50 °C [14] compared to the conventional silica gel. While there is research on polymer sorbent itself, there is no research on performance of overall system consisting of DAHU with polymer sorbent as well as heat source system including chillers and CHPs.

In hot and humid climate such as in Japan, handling latent heat load to the desired absolute humidity satisfactorily is required. However, when outdoor latent heat load and indoor latent heat load are processed only by dehumidification wheel coated with polymer sorbent, there are disadvantages such as larger diameter for dehumidification wheel or higher regeneration temperature.

Stephan [15] conducted experiments with polymer sorbent desiccant wheels compared with conventional silica gel desiccant wheels. The results show that when the air condition entering dehumidification wheel is high relative humidity, even if regeneration temperature is low, greater dehumidification is achieved with polymer sorbent than silica gel. In order to overcome the disadvantages mentioned above, pre-cooling coil is installed before dehumidification wheel. It is estimated that furnishing pre-cooling coil before dehumidification wheel enables higher relative humidity of the air entering dehumidification wheel, which results in great performance of polymer sorbent. Although this idea requires pre-cooling coil to dehumidify the air by condensation, it is desired to set the chilled water temperature as high as possible.

DAHU is one of the most important solution for effective heat use from CHP, however operation data set is in shortage and there is little knowledge how to design DAHU for office buildings. Therefore, it is essential to analyze and evaluate DAHU including chilled water heat source and hot water heat source because the behavior and performance of DAHU are determined by the balance of DAHU concerning regeneration temperature and chilled water temperature. Typically, in Japan, hot water to DAHU is supplied from CHP and chilled water is supplied from chiller, therefore it is also essential to evaluate DAHU including efficiency of chiller and CHP. When