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Energy and Buildings 38 (2006) 447–453
ENERGY and BUILDINGS
www.elsevier.com/locate/enbuild

Performance analysis on a hybrid air-conditioning system of a green building

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Received 23 May 2005; received in revised form 25 July 2005; accepted 5 August 2005

Abstract

This paper presents the performance analysis on a hybrid air-conditioning system according to the hybrid building energy system of the green building demonstration project in Shanghai, in which a 150 m^2 solar collector is used to power two 10 kW adsorption chillers, a vapor compression heat pump is used to cool air in the evaporating end while the condensing heating at about 80 °C is fully used to regenerate a liquid desiccant dehumidification system. In the hybrid system, the sensible cooling to the air is treated mainly by solar adsorption cooling and vapor compression cooling, whereas the latent heat is treated by the liquid desiccant dehumidification system with regeneration from the condensing heat of the heat pump. The results show that the performance of this system is 44.5% higher than conventional vapor compression system at a latent load of 30% and this improving can be achieved by 73.8% at a 42% latent load. The optimal ratio of adsorption refrigerating power to total cooling load for this kind of hybrid systems is also studied in this paper.

Keywords: Liquid desiccant; Hybrid air-conditioning; Adsorption refrigeration; Solar energy; Performance analysis

1. Introduction

Up to now, most of the air-conditioning systems all over the world are based on conventional vapor compression cooling devices. In order to overcome the latent load, the air temperature must be decreased to be lower than its dew point which requires the evaporating temperature of air conditioner or chillers as low as about 5 °C. This temperature is much lower than normally required for air-conditioning (room air temperature about 26 °C, evaporating temperature about 15 °C), and consequently reduces the coefficient of performance and then leads to a large amount of energy consumption. If the latent heat and sensible heat for cooling purposes can be treated independently, for example, if air is dehumidified by a desiccant system (latent heat), the evaporating temperature for vapor compression system could then be raised up to 15 °C (sensible cooling). If the sensible cooling is at 15 °C evaporating temperature, and the latent heat could be treated by waste heat or solar energy, the electrical COP of the air-conditioning system could then be increased obviously.

Hybrid systems, which consist of desiccant cycle and vapor compression cycle, are very attractive due to its energy-saving and its function to kill virus to make air clean. Such combination systems reduce the moisture content of air by liquid desiccant directly. Liquid desiccant dehumidification can be driven by low-grade energy such as solar energy, waste heat of industrial processes and terrestrial heat so that it consumes little primary power. Hybrid systems are able to control humidity and temperature independently, as a result, the evaporating temperature can be increased up to 15 °C, and hence the COP of a chiller will be significantly improved. In addition, hybrid systems avoid condensing water on coils and prevent devices from corrupting, so the maintenance costs can be cut down.

Many investigations have been carried out on the feasibility and energy-saving potential of hybrid air-conditioning systems. In 1986 Howell et al. [1] drew a conclusion that hybrid systems with a vapor compression cycle for sensible cooling and a liquid desiccant cycle for latent heat removal could reduce energy consumption by 35% if compared with single vapor compression systems. A kind of solar powered hybrid vapor compression with liquid desiccant has been studied by Yadav [2] who gave a simulating result that the hybrid system could save energy about 53% at 40% latent load and this saving increased to 80% at 90% latent heat load compared with typical vapor compression

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doi:10.1016/j.enbuild.2005.08.004

Nomenclature

C	cooling required (kW)
COP	coefficient of performance
COPR	relative coefficient of performance
E	electricity power (kW)
ECOP	electrical coefficient of performance
L	latent load (kW)
Load	total load of the building (kW)
Q	heat supplied by condenser (kW)
S	sensible load (kW)
TCOP	thermal coefficient of performance
W	refrigerating power (kW)

Greek symbols

η_i	efficiency of HEi (i = 1, 2, 3 as index)
λ	the optimal match factor
Φ	ratio of latent load to total load

Subscripts

con	conventional (system)
h	heat
in	indoor
out	outdoor air
r	refrigeration
sys	system

Superscripts

a	actual (load)

system. Dai et al. [3] studied a hybrid cooling system which combined desiccant cooling and vapor compression air-conditioning together in simulation and experimental methods and got the result that this system had 20–30% more cooling production than conventional vapor compression system alone. Kinsara et al. [4,5] proposed a quite complete hybrid system and made a parametric analysis in details, the research result was of important significations for optimizing designs of liquid desiccant hybrid air-conditioning systems.

Adsorption refrigeration is one type of refrigeration technologies which make good use of very low-grade thermal energy, it can effectively produce cooling when the temperature of heat source is up to 60 °C if silica-gel and water are used as working pair, so it is very suitable for efficient solar energy utilization. If adsorption refrigeration is introduced into hybrid air-conditioning system, the performance can be further improved. The adsorption chillers referred in this paper have two adsorption/desorption chambers that work alternatively so the chillers can produce cooling continuously. The cooling production increases as the temperature of heat source increases, and the rated refrigerating 10 kW cooling power is achieved when the temperature of heat source reaches 85 °C.

The green building demonstration project contains many green energy technologies including solar powered air-conditioning, solar hot water supply, solar heat driven floor radiation heating, solar electricity generating, solar enhanced natural ventilation, solar lighting and so on. Shanghai Jiao Tong University designed the solar powered hybrid energy system for air-conditioning, heating, ventilation and hot water supply. The solar powered system combined with the liquid desiccant dehumidification system designed by Tsinghua University and Institute of Architecture Science and Technology in Shanghai deals with the overall load of the green building in summer.

2. Hybrid air-conditioning system of green building

2.1. Description of the system

Fig. 1 shows a schematic of the system, which is composed of three subsystems.

1. Vapor compression heat pump, in which chilled water with temperature of about 15 °C is produced from evaporator and hot water with temperature of above 65 °C is obtained from condenser simultaneously. The cooling is used to cool the supply air while the condensing heat is used to regenerate the liquid desiccant.
2. The solar system, which contains 150 m^2 solar collector array, a hot water storage tank, two 10 kW adsorption chillers and water cooling tower for the adsorption chillers.
3. Liquid desiccant dehumidification system, which is composed of dehumidifier, heat exchanger HE2 to recover energy and regenerator [6]. In this liquid desiccant loop lithium bromide solution is used as liquid desiccant due to its high energy storage capacity of over 1000 MJ/m^3 [7].

Fig. 2 shows the photographs of the solar powered green building and two adsorption chillers installed. The whole system had been working since October of 2004.

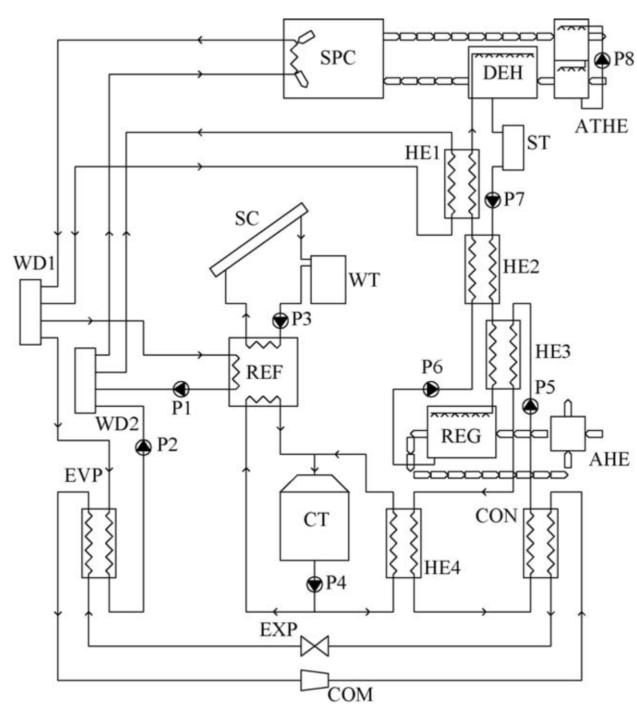

Fig. 1. Schematic diagram of hybrid air-conditioning system of green building.