Applied Thermal Engineering 30 (2010) 1659–1665

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Effect of neutral temperature on energy saving of centralized air-conditioning systems in subtropical Hong Kong

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ARTICLE INFO

Article history:
Received 7 December 2009
Accepted 15 March 2010
Available online 25 March 2010

Keywords:
Energy saving
Comfort air speed
Neutral temperature
Thermal comfort
Air-conditioning

ABSTRACT

Higher room temperature can still let the occupants have a neutral thermal sensation if higher air speed is provided. With a suitable scheme of neutral temperature and comfort air speed, reduction of energy consumption of the central chiller plant may surpass the additional energy requirement of the air side equipment, then both energy saving and thermal comfort can be achieved for the entire air-conditioning system. To evaluate this, the energy consumptions of a centralized air-conditioning system using the common air side alternatives were studied for the subtropical Hong Kong. The alternatives are variable air volume (VAV) system, constant air volume (CAV) system and fan coil (FC) system. Each of them was associated to a central chiller plant to serve a high-rise office building. The studying range of the room air temperature was from 23 °C to 30 °C. It is found that the VAV and FC systems can provide both thermal comfort and energy saving for higher room temperature, but CAV system is not feasible when the room air temperature is above 27 °C. If the indoor air speed threshold is considered, the neutral temperature can be brought up to 26.5 °C, and the energy saving potentials of VAV and FC systems would be 12.9% and 9.3% respectively.

1. Introduction

It seems not easy to have a balance between thermal comfort and energy saving for buildings with centralized air-conditioning systems. Comfortable indoor room temperature should not be high as perceived by general occupants. The government has advocated the "Energy Conservation Charter" for promoting energy saving of air-conditioning system in Hong Kong, the key guideline is to raise the room temperature to 25.5 °C for the participating organizations [1]. But a study has found that the neutral temperature is 23.6 °C in the air-conditioned office environment in the subtropical Hong Kong [2]. Hwang et al. [3] conducted a field study to understand the priority between thermal comfort and energy saving in hot humid regions. It is found that thermal comfort is more important and it should be ensured first, energy saving is just the second. This implies that people may prefer thermal comfort rather than energy saving if these two requirements cannot be compromised. Dounis and Caraiscos [4] proposed an advanced control system to provide both energy and comfort management. The thermal comfort was maintained by the conventional PMV model, which has been queried about its representativeness in different cultures and climatic regions [5,6].

To balance thermal comfort and energy performance, Yamtraipt et al. [7] conducted thermal comfort field studies to evaluate the neutral temperature by considering additional factors of acclimatization and education level of building occupants. The proposed higher room temperature settings would be used to promote local energy saving in air-conditioning systems. Atthajariyakul and Lertsatittanakorn [8] proposed to install small fans before the building occupants so that the neutral temperature can be possibly elevated to 28 °C and energy consumption of air-conditioning systems can be reduced. Toftum et al. [9] studied the occupant performance in buildings with and without mechanical cooling, and thermal sensation was used as an input to the estimation of occupant performance. It is found that the occupant performance is only slightly lower without mechanical cooling, showing that the effect of air speed can compensate the increase of room temperature and provide an acceptable comfort level.

It is true that higher room temperature can let the occupants have the neutral thermal sensation if higher air speed is provided. In fact apart from the air temperature, there are five more classical factors of thermal comfort, including the air speed, relative

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doi:10.1016/j.applthermaleng.2010.03.024

Nomenclature

$COP_{avg,w}$ yearly averaged COP of the water side system
$COP_{avg,w\&a}$ yearly averaged COP of the entire centralized air-conditioning system
Q cooling load (kJ/h)
W_a power input of air side equipment (kJ/h)
W_w power input of water side equipment, including chillers, chilled water pumps, condenser water pumps and cooling towers (kJ/h)

humidity, mean radiant temperature, clothing insulation and activity level of occupants. However, Givoni et al. [10] conducted a series of thermal comfort studies and found that relative humidity has a minimal effect to neutral comfort of the people living in the hot humid regions, including Japan, Singapore, Thailand and Indonesia. In a certain functional area, the clothing insulation and activity level of different occupants would be similar. If the mean radiant temperature is supposed to be close to the air temperature, particularly in an indoor environment, then the air speed can be a factor that affects the thermal comfort of occupants. Therefore it is necessary to study about using an effective scheme of comfort air speed to achieve both thermal comfort and energy saving of the air-conditioning system.

Hong Kong is a metropolis in subtropical climate region, full of high-rise buildings. For the local office buildings, it is common to design a multiple chiller plant for supplying chilled water to the air side equipment, which is installed around in different floors or zones. In the air side design, variable air volume (VAV) system, constant air volume (CAV) system and fan coil (FC) system are the common alternatives for performance and economic considerations. Fig. 1 shows the schematic diagram of the VAV, CAV and FC systems associated with a central chiller plant. From the viewpoint of energy consumption, the difference of the VAV, CAV and FC systems is their equipment involved. In the VAV or CAV system, energy consumption is mainly originated from the supply air fan of the air handling unit. In the FC system, it is also related to the supply air fans, which are installed in the small fan coil units scattered around the air-conditioned spaces.

In the VAV system, the supply air flow rate is variable and decreased according to the part-load conditions, so the energy consumption of the supply air fans would be reduced. If the supply air flow reaches the minimum threshold, the chilled water flow rate entering the cooling coil would be reduced so that the room temperature can be maintained. In the CAV or FC system, the flow rate hence the energy consumption of the supply air fans is generally constant. So during the part-load conditions, reduction of chilled water flow rate entering the coil would be directly applied. This subsequently reduces the energy consumption of the chillers, as well as the associated pumps and cooling towers. The coefficient of performance (COP) of the chiller plant would then be enhanced, but it depends on the type of air side design. Therefore the energy consumption of these three alternatives of air side design, as well as that of the entire air-conditioning system, would be different due to higher room air temperature and supply air flow rate. Generally there is energy saving in the chiller plant by applying higher room temperature associated with higher supply flow rate based on comfort air speed. However, higher supply air flow rate would lead to higher energy consumption of the air side equipment accordingly. Owing to this dilemma, it is worth studying whether there is energy saving potential of the centralized air-conditioning system from a holistic viewpoint.

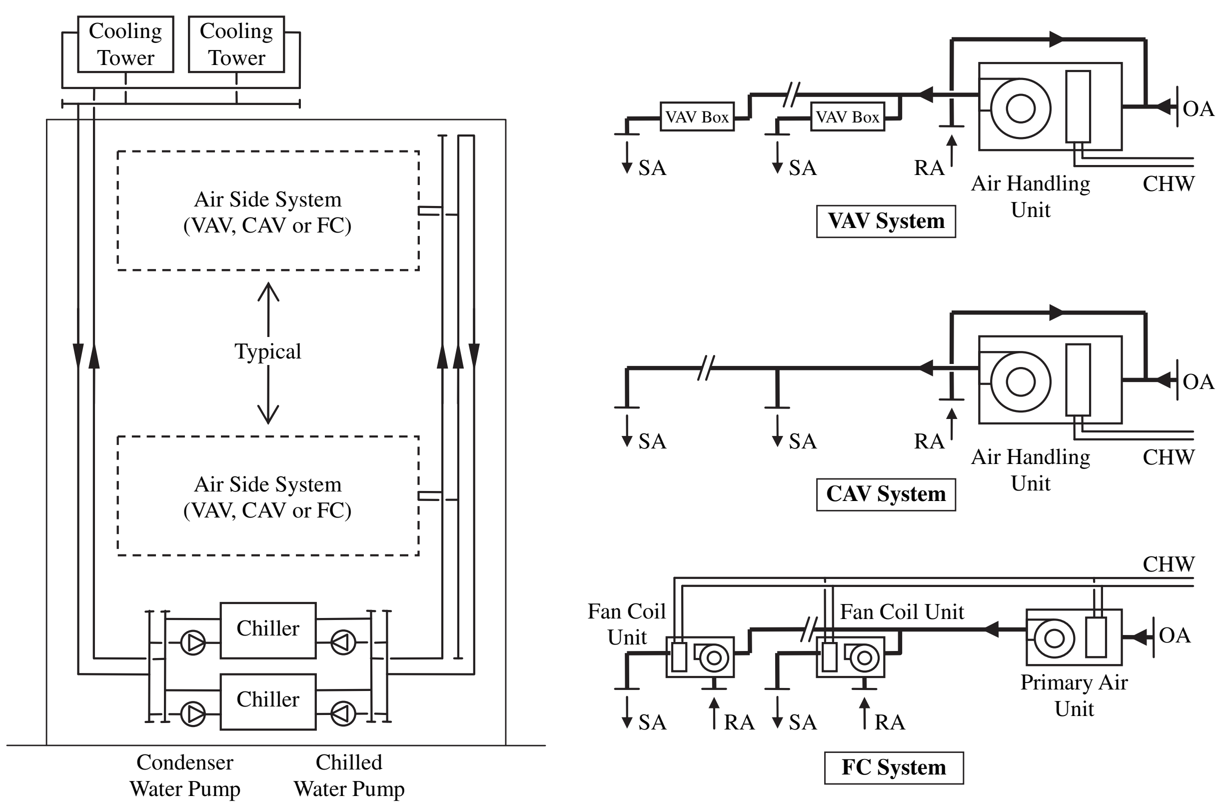

Fig. 1. Schematic diagram of typical centralized air-conditioning system for high-rise buildings, comprising a central chiller plant and air side system (abbreviation: CHW: chilled water supply and return; OA: outdoor air; RA: return air; SA: supply air).