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A new method of determination of indoor temperature and relative humidity with consideration of human thermal comfort

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ABSTRACT

A new method is described in this article for selecting indoor temperature and indoor relative humidity to achieve minimum energy consumption for a required indoor thermal comfort level which is evaluated with indoor effective temperature. This method is derived from a central air-conditioning system and is based on our investigation that under a same indoor effective temperature, the system cooling load and the system energy consumption increase with an increase of indoor temperature. As such, energy consumption cannot be reduced with increasing indoor temperature for a given human thermal comfort level. In order to reduce energy consumption while keeping a same indoor thermal comfort level, indoor temperature and relative humidity may be determined with the proposed method described in this article. With the proposed method, a parameter variation study has also been conducted, which suggests that for a given indoor effective temperature, a combination of high indoor relative humidity and low indoor temperature be generally taken. The proposed method is based on the central air-conditioning system; yet it can be easily extended to other systems.

1. Introduction

1.1. The objective of the study

The use of air-conditioning equipment has been increasing quickly in recent years around the world, especially in developing nations. The energy consumption of buildings in developed countries comprises 20–40% of total energy use [1,2]. The increasing demand for building services and human comfort levels has spurred energy consumption worldwide. How to reduce energy consumption of air-conditioning buildings is an imperative issue to be addressed.

For an air-conditioned building, a major part of energy consumed is for the heating and air-conditioning system. In some climate regions where cooling takes the major energy consumption in air-conditioned buildings, the higher the cooling load, the higher the energy consumption. The cooling load in a central air-conditioning system is usually composed of three parts: indoor cooling load, fresh-air cooling load, and reheat cooling load, among which the indoor cooling load is generated by indoor heat gain and is related to indoor temperature. Increasing indoor temperature can reduce indoor cooling load due to the reduction of indoor heat gain transferred through the building envelope. Therefore, indoor temperature is required to be set greater than or equal to 26 °C nowadays in air-conditioning rooms of China for reducing energy consumption.

The increase of indoor temperature will however affect the indoor human thermal comfort level. In the air-conditioning system design, the human thermal comfort is related to the concept of effective temperature (ET*), which combines temperature and humidity into a single index so that two environments with same ET* evoke the same thermal response even though they have different temperatures and humidities, but they must have the same air velocities [3]. From the viewpoint of indoor thermal environment design, effective temperature represents the human thermal comfort level. It should be noted that surely there are many other factors that influence human thermal comfort, notably air velocity. However, as far as air velocity, its effect may be replaced by humidity. It is common sense that for a given human thermal comfort level, increase in indoor temperature needs to be accompanied with decrease in indoor humidity. It seems to be such that indoor temperature and indoor relative humidity are two major important parameters to be chosen.

The overall objective of the study described in this article is to provide a method for determining indoor temperature and indoor relative humidity given effective temperature ET*, which

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represents human thermal comfort. The study was based on a central air-conditioned building and a climate region such as Guangzhou and other southern parts of China.

1.2. Related work

As the indoor thermal environment has a direct effect on the building energy consumption [4,5], several studies have been carried out to investigate the relationship between building energy consumption and human thermal comfort [5–9]. Holz et al. [4] studied the relationship between building energy consumption of three energy conservation measures and human comfort using DOE-2 building energy performance simulation software. Their sensitivity analysis of the six comfort factors showed that the clothing worn by occupants, the activity level, air temperature, and mean radiant temperature all have significant effects on human thermal comfort. Humidity and air velocity play rather small roles in comparison, but they seem to regulate the sensitivity of the other four factors and are therefore important. The study of Yang and Su [6] indicated that energy consumption can be reduced by using higher indoor air velocities while maintaining the same comfort level when tuning up the indoor temperature setting. Corgnati et al. [8] studied the relationship between the building energy demand and the indoor thermal environment comfort level. The energy demand related to different human thermal comfort levels, expressed in terms of predicted mean vote (PMV), was calculated for a typical office room. Their study showed that significant energy reduction can be achieved in buildings that are not fully controlled mechanically, with adaptive comfort theory for a same percentage of dissatisfied people. Martín et al. [9] experimentally investigated the relationship between human thermal comfort and building energy consumption, in which a semi-indirect evaporative cooler (SIEC) and a heat pipe (HP) system were applied to reduce energy consumption. Tsutsumi et al. [10] experimentally investigated the effects of low humidity on human comfort after a step change from warm and humid condition to thermally neutral condition at constant effective temperature and concluded that the effects of humidity on thermal comfort can be estimated by using effective temperature. Becker et al. [11] experimentally studied the effect of extremely hot and arid conditions on human thermal perception and overall comfort using the Fanger's energy balance model. The energy balance model was used to calculate the average thermal perception under the conditions of a set of indoor parameters during certain activities. Their study showed that the calculated and observed heat stress can differ considerably under extremely hot and arid conditions.

Thermal comfort is not only dependent on physiological but also on psychological factors. Chowdhury et al. [12] made a thermal comfort analysis and simulation on office building using low energy cooling technology. Chun et al. [13] investigated the dynamic relationship between thermal history and thermal comfort sensations and found that thermal history (i.e. daily temperature exposures) affects the thermal sensation in space. The group of people exposed to hotter temperatures responded with cooler thermal sensations than the group exposed to cooler temperatures under the same thermal conditions. Amai et al. [14] investigated the thermal sensation and comfort with different task conditioning systems and found that male subjects tended to prefer cool and fast airflow, while female subjects tended to prefer warm and slow airflow. The study reported by Kosar and Dumitrescu [15] showed the effect of humidity on refrigerated loads in American supermarkets and concluded that decreasing store humidity levels can reduce energy consumption. Sekhar [16] investigated the influence of supply air temperature difference (the temperature difference between indoor air and supply air) on energy consumption of a hypothetical building in a tropical climate and found that the total power requirement, comprising additional cooling, reheating, and higher fan power, for a design with supply air temperature difference of 5 °C is as high as a factor of 2.2 of the total power for a design with supply air temperature difference of 8 °C.

It can be seen from the above discussion that although there are many studies on the relationship between indoor thermal comfort and energy consumption in the literatures, few studies reported the relations among indoor design parameters (particularly, indoor temperature and indoor relative humidity), energy consumption, and indoor human thermal comfort. A science-based guideline does not seem to be available to determine indoor temperature and indoor relative humidity with consideration of human thermal comfort. The study presented in this paper was to answer the following questions. (1) Under a same thermal comfort condition, whether energy consumption in a central air-conditioning system we considered can be reduced by increasing indoor temperature and decreasing indoor relative humidity? (2) How indoor temperature and indoor relative humidity can be more rationally and quantitatively determined for a required thermal comfort level with the objective of a minimum energy consumption.

1.3. The study context

The study presented in this article took a three-story office building using a central air-conditioning system as an example. The office building is located in Guangzhou, China. The total plane area of this building is 2673 m^2. The building was supposed to hold 188 people. The outdoor air (fresh air) required for indoor air quality was taken to be 30 m^3/(h person). The air-conditioning process is plotted in Fig. 1, in which outdoor air (state W) is mixed with return air (state N) to state point C. The mixed air is further cooled down and dehumidified from state C to apparatus dew point (state L), and then reheated to supply air (state O), and further changed by following the load ratio line ε to the required indoor design (state N). The outdoor air (state W) is determined using the summer design dry-bulb and wet-bulb temperatures from the HVAC Code issued by the Ministry of Construction of China [17]. In particular, the summer design dry-bulb and wet-bulb temperatures in Guangzhou are 33.5 and 27.7 °C, respectively. The indoor air (state N) is determined by the required indoor dry-bulb temperature and relative humidity according to the effective temperature used in the investigation.

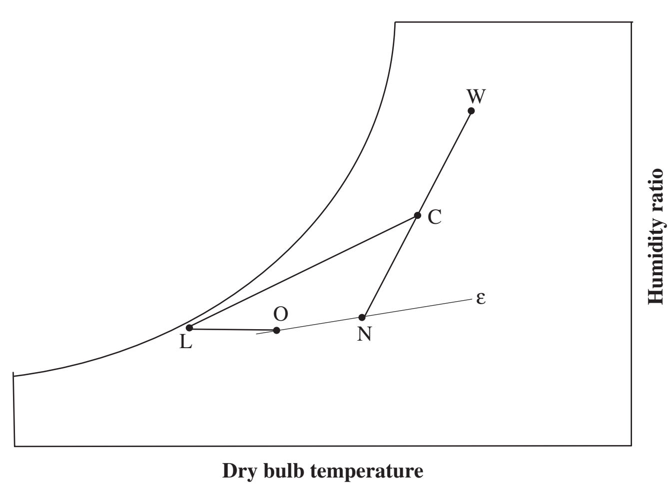

Fig. 1. Air-conditioning process in central air-conditioning system.