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Enthalpy estimation for thermal comfort and energy saving in air conditioning system

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Abstract

The thermal comfort control of a room must consider not only the thermal comfort level but also energy saving. This paper proposes an enthalpy estimation that is conducive for thermal comfort control and energy saving. The least enthalpy estimator (LEE) combines the concept of human thermal comfort with the theory of enthalpy to predict the load for a suitable setting pair in order to maintain more precisely the thermal comfort level and save energy in the air conditioning system.

Keywords: Thermal comfort; Least enthalpy estimator (LEE); Air conditioning

1. Introduction

Most thermal comfort models of heat exchanges between the body and its environment are based on the classical theory of heat transfer. Both steady state energy balance and two node transient energy balances are widespread models [1]. These models assume that the body is uniform, and that heat production of the body is transferred to the environment. According to both models, the most factors influencing thermal comfort condition depend on four environmental factors and two personal factors. The four environmental factors are air temperature, mean radiant temperature, humidity and air velocity. The two personal factors are activity level and clothing insulation. Many studies [2–4] try to implement these thermal comfort models. However, there are three main reasons for the complexity of thermal comfort calculation. First, the human thermal comfort sensation is subjective. Second, many variables affecting the sensation of thermal comfort are hard to measure with precision. Third, activity level and clothing strongly depend on personal preferences [5]. Therefore, it is hard to detail these models in an actual environment. The study in Ref. [2] indicated that if activity level, clothing insulation and air velocity were constant and the mean radiant temperature was assumed to be the air temperature, then air temperature and relative humidity are the dominant factors affecting the thermal comfort sensation.

An air conditioning (A/C) system provides the occupants with a thermal comfort condition. The demands for air conditioning systems consume a large amount of energy in buildings. Most air conditioning equipments in buildings are inefficient for energy saving and consume huge amounts of energy [6,7]. Thus, providing more effective control of air conditioning systems and improving the energy efficiency of air conditioning equipment are important for energy saving [7–10]. The prediction of room thermal load makes it possible to fulfill the goals of energy efficiency. Generally, the temperature control and the humidity control are separated in air conditioning control systems. In most existing air conditioning systems, only the temperature control, especially the thermostat, is used. Normally, the temperature setting is constant, which cannot make occupants comfortable [11]. It not only fails to provide a good thermal comfort level for the occupants but also neglects the consideration of energy saving in

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those systems [6,12,13]. However, the priority for saving energy in air conditioning systems is to determine the thermal loads. Thermal load changes can be regarded as alterations of the air enthalpy in the room [14]. Thus, the concept of thermal comfort level with the theory of enthalpy is good for saving energy and maintaining the thermal comfort level.

Thermal comfort control tends to decrease the energy consumption of air conditioning systems that maintain low humidity and penalize systems that maintain high humidity [15]. Generally, an effective temperature indicates the rate at which the dry bulb temperature can be increased with decreasing relative humidity while maintaining the same thermal comfort level. The lower the relative humidity, the higher the dry bulb temperature could be for the same thermal comfort level. Thus, a lower relative humidity can compensate for a higher dry bulb temperature without affecting the thermal comfort sensation. The rational reason behind the energy saving is that by lowering the relative humidity in the room, a constant thermal comfort level can still be maintained with a higher dry bulb temperature [16]. Hence, due to the higher temperature setting, the energy consumption of the air conditioning system can be reduced. Meanwhile, the thermal comfort condition is time dependent. Thus, the setting of dry bulb temperature and relative humidity should be properly adjusted for constantly changing room conditions.

In this paper, a least enthalpy estimator (LEE), which utilizes the concept of thermal comfort and the theory of enthalpy, is proposed for providing a suitable setting for the effective temperature for air conditioning control systems to achieve thermal comfort and energy saving.

The paper will first discuss thermal comfort control and energy saving. The least enthalpy estimator (LEE) is proposed. In Section 3, the enthalpy estimation is divided into three decisions and solved by the LEE, respectively. Finally, the experimental result using the LEE based thermal comfort controller is presented.

2. Thermal comfort control and energy saving

Based on both thermal comfort and energy saving requirements, the first step in saving energy for air conditioning systems is to analyze the room thermal load. The load change in a room can be treated as an alteration of the air enthalpy in the room. Therefore, the theory of enthalpy is suitable for predicting the future air conditions of a room. The enthalpy estimation is conducive for thermal comfort control and energy saving.

2.1. Effective temperature in thermal comfort control

ASHRAE 55-1992 [17] defined thermal comfort as the condition of mind that is satisfied with the thermal environment. Many factors influence human thermal comfort and response in thermal space. A thermal comfort model depends mainly on a complex interaction of dry bulb temperature, mean radiant temperature, air velocity, relative humidity, clothing insulation and activity level. Since heat production by the body is directly proportionate to human activity level, heat exchange between the body and the environment should occur in order to avoid discomfort due to any small difference in the body temperature. Thus, in some typical indoor applications, for people wearing similar clothing insulation for similar activity in the same climate, both the activity and the clothing factor can be assumed to be constant. In ASHRAE 55-1992, a standard set of conditions representative of typical indoor applications is used to define a thermal comfort zone for summer. The only variables affecting thermal comfort are air temperature and relative humidity.

The purpose of ASHRAE 55-1992 is to specify the combinations of indoor space environment and personal factors that would produce thermal environmental conditions that are acceptable to 80% or more of the occupants within a space. Table 1 shows the optimum operative temperature for people in typical summer clothing during sedentary and moderate activity. It also indicates that a metabolic rate is 1.2 met or less at 50% rh and a mean air velocity of 0.15 m/s or less. The operative temperature is similar to the ambient air temperature, while the mean radiant temperature is assumed to be approximated as the ambient air temperature. During summer seasons, the typical clothing in commercial establishments consists of light slacks and a short sleeve shirt with the clothing insulation values of about 0.5 clo.

Table 1
Optimum operative temperature for people during light, primarily sedentary activity (⩽1.2 met) at 50% rh and mean air speed ⩽0.15 m/s (source: ANSI/ASHRAE Standard 55-1992)

Season	Description of typical clothing	I_{cl}	Optimum operative temperature	Acceptable operative temperature
Summer	Light slacks and short sleeve shirt	0.5 clo	24.5 °C	23–26 °C

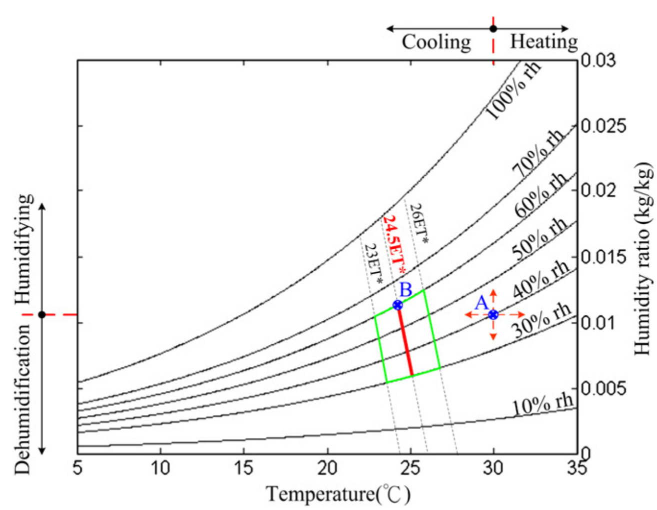

Fig. 1. Thermal comfort control criterion on the psychrometric chart.