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Effects of return air vent height on energy consumption, thermal comfort conditions and indoor air quality in an under floor air distribution system

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ABSTRACT

In this article, an under floor air distribution (UFAD) system with separate return and exhaust air vents is investigated. The proper angle of the swirl inlet diffuser is selected by comparing the general thermal comfort conditions obtained from three different inlet angles. At this proper inlet angle, the effects of return air vent height on energy consumption, thermal comfort conditions, and indoor air quality (IAQ) are investigated. To this end, thermal comfort indices (PMV–PPD), local thermal discomfort index (temperature gradient in vertical direction), and IAQ index (mean local age of air) are probed by CFD methods. Energy consumption reduction in an UFAD system equipped with a return air vent compared to MV system is 10.9, 15.3, 18.9, and 25.7% when the return air vent height is set at 2.0, 1.3, 0.65, and 0.3 m, respectively. Reducing the height of return air vent from ceiling to floor leads to an increase in exhaust air temperature and temperature gradient at the vertical direction. It is found that selection of the 1.3 m height from floor (upper boundary of occupied zone in seated mode) for return air vent height will cause a 15.3% reduction in energy consumption and would maintain the thermal comfort and IAQ in the specified range.

1. Introduction

Providing a healthy and comfortable place for occupants while increasing the building efficiency is the main focus of buildings design. Global warming is an important criterion that should be considered with respect to this objective; therefore heating, ventilation, and air conditioning systems should consume the least possible amount of energy.

Air distribution system is vital in indoor air quality (IAQ), as far as energy consumption, space organization, and interior layout are concerned. In general, there are three types of air distribution systems: mixing ventilation (MV), stratum ventilation (SV), and displacement ventilation (DV).

Under floor air distribution (UFAD) system is a newly developed system which has been widely applied in new commercial buildings. UFAD systems are similar to MV systems in terms of the equipment used at the cooling and heating plants and primary air handling units (AHU). Difference in location is the only factor between the UFAD and MV systems regarding air inlet [1]. In MV systems, air inlet is at the ceiling which ideally causes a well-mixed indoor air, but in UFAD systems air inlet is on the floor plenum and air is directly supplied to the elevation of the allowable occupied zone. Actually, UFAD systems use the empty space between the space floor and the raised access floor (Fig. 1).

In UFAD systems, floor diffusers mounted on the raised access floor are used for air distribution. Here, the inlet air temperature is higher than that of the MV systems (about 3–4 °C). The inlet air velocity of UFAD systems is higher than that of the customary displacement ventilation systems, but it is much lower than that of the MV systems [2].

Due to the significance of these systems, various aspects of them are investigated. Xu and Niu [3] proposed a numerical procedure for predicting annual energy consumption of the UFAD system. Xu and Niu in their study, concluded that in comparison to the MV system, the UFAD system obtains its energy saving potential from the following three factors: an extended free cooling time, a reduced ventilation load, and an increased coefficients of performance (COP) for the chillers. Daly [4] suggested the following three strategies for taking the best possible advantages from UFAD while keeping the initial cost at a minimum: (1) minimize the duct work in the

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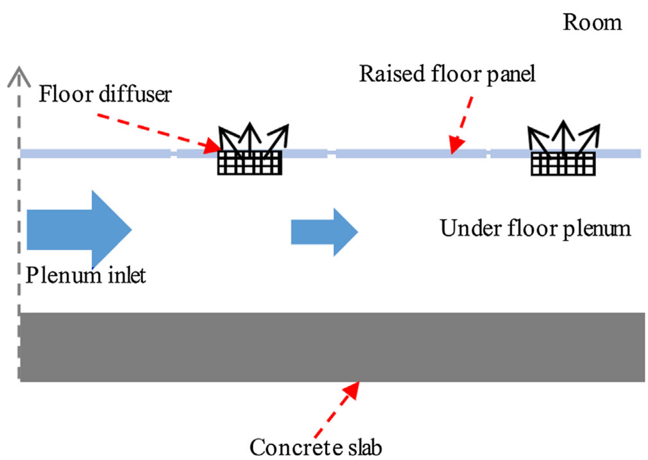

Fig. 1. Under floor plenum schematic.

plenum, (2) prevent plenum leakage, and (3) keeping the airflow within range. Bauman and Daly [5] compared the UFAD and MV systems based on their performance. Alajmi and El-Amer [6] investigated the energy performance of UFAD systems in commercial buildings for various inlet air temperatures. Alajmi and El-Amer reported that UFAD systems demonstrate significant energy saving compared to MV systems. Jaakkola et al. [7] found that the ability to control temperature by every occupant is an effective manner to improve thermal comfort of occupants and decrease sick building syndrome (SBS) in UFAD systems. Kuo and Chung [8] investigated the effects of inlet diffusers and outlet vents position on occupants' thermal comfort in the occupied zone. Lam and Chan [9] reported that the outlet vent position has a significant impact on the thermal stratification in a gymnasium and the annual cooling load of the system. Kim et al. [10] investigated the occupants' thermal comfort conditions by an UFAD system in a big indoor environment. According to Kim et al., the UFAD system is capable of creating smaller vertical variations of air temperature and a more comfortable environment than conventional overhead air distribution (OHAD) systems do.

Temperature gradient in vertical direction is one of the most important issues in occupants' thermal comfort, and the UFAD systems are prone to reach an unacceptable value of temperature gradient in vertical direction. Zhang et al. [11] and Fong et al. [12] reported that well designed UFAD systems could provide a good thermal environment.

Based on the aforementioned studies, there are several potential advantages in using UFAD systems compared to MV systems like: improved thermal comfort, improved IAQ, and reduced life-cycle costs.

The vents position has a great effect on the performance of UFAD systems. Apart from special cases, there should be return air vents installed in UFAD systems, but in most of the previous studies, the return and exhaust air vents are combined as one unit. It is observed that UFAD systems with separate return and exhaust air vents at different elevations (Fig. 2) lead to a considerable energy consumption reduction [13].

In this study, an UFAD system with separate return and exhaust air vents is investigated. Numerical simulations are carried out for three different angles of the swirl inlet diffuser. The correct swirl inlet angle of the diffuser is selected based on the occupants general thermal comfort conditions; next, the effects of return air vent height on thermal comfort conditions, IAQ and energy consumption optimization is investigated by applying the selected right angle.

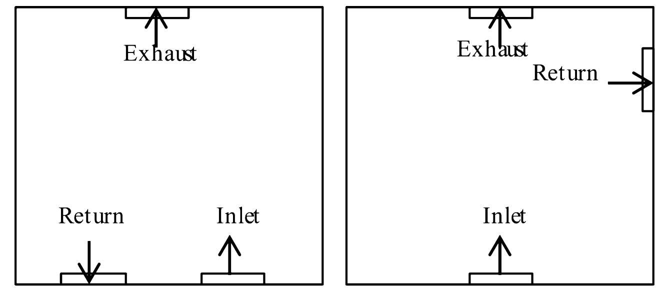

Fig. 2. Schematic of UFAD systems with separate return and exhaust air vents [13].

2. Methods

2.1. Model description

A room that is equipped by UFAD system is used for validation procedure. This room of 5.16 m length, 3.65 m width, and 2.27 m height (Fig. 3) is investigated experimentally by Kobayashi and Chen [14]. The conditioned cool air is delivered into the room by swirl diffusers located at the floor elevation. The total air change rate and the air supply temperature are 4.4ACH and 19 °C, respectively. Four fluorescent lamps are used for lightning; heat emitted by each lamp is 68 W. Two hollow blocks are used as occupants with 75 W heat output. Heat emitted by PC 1 and PC 2 simulators is set to 108.5 and 173.4 W, respectively.

The boundary temperatures are specified to represent the actual temperatures of the room surfaces obtained from experimental study (Table 1). It is assumed that in the exhaust vent, the average static pressure is the same as the atmospheric pressure.

2.2. Simulation method

Airpak 2.0, is adopted as the main simulating tool, which is an accurate, quick, and easy-to-use design tool that simplifies the application of state-of-the-art airflow modeling technology in designing and analysis of ventilation systems which are required for IAQ, thermal comfort, health and safety, air conditioning, and/or contamination control solutions [15].

Here, the finite volume method with structured grid is adopted in solving procedure, and semi-implicit method for pressure-linked equations (SIMPLE) algorithm is applied in resolving the pressure and velocity coupling.

2.3. Thermal comfort index

The idea of adopting the analytical thermal comfort models is rooted in the 1960 [16]. In 1970, the first analytical model which predicts the thermal comfort conditions of occupants was presented by Fanger [17]. Fanger's model combines the following four physical variables: air temperature, air velocity, mean radiant temperature, and the relative humidity and the two personal variables

Table 1
Walls boundary temperature (°C) [14].

Wall	Temperature (°C)
North	26.8
South	26.8
East	28.6
West	25.8
Floor	25
Ceiling	27.4