Prediction of thermal comfort, IAQ, and Energy consumption in a dense occupancy environment with the under floor air distribution system

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ABSTRACT

This study investigates an under-floor air distribution (UFAD) system with combined and separate return and exhaust air vents regarding thermal comfort, indoor air quality (IAQ), and energy consumption. UFAD system is used in a large indoor environment (dense occupancy). CFD methods are used to predict thermal comfort conditions, IAQ, and energy consumption in this space. Based on the results, swirl inlet diffusers can lead to an acceptable temperature gradient in the vertical direction. By precisely considering thermal comfort conditions, and IAQ made by swirl inlet diffusers, opting the upper boundary of the occupied zone (1.7m) for return air vent position (which is the optimum case study among all the examined case studies) can lead to the appropriate results. Moreover, the optimum return air vent position in this UFAD system can result to 10.5 percent reduction in the amount of energy consumption compared to the mixing ventilation system.

INTRODUCTION

Under Floor Air Distribution (UFAD) systems are among the newly defined ventilation systems. These systems use open spaces, called plenums between the concrete slab and raised access floor to supply conditioned air. The conditioned air is delivered into the occupied zone through floor diffusers, which are mounted on the raised access floor (Fig. 1).

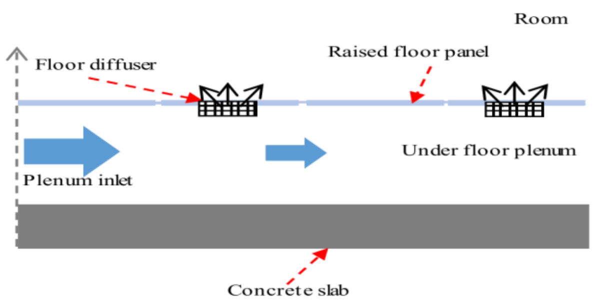

Fig. 1. Under floor plenum schematic

These systems are offered an alternative to overhead, mixing ventilation (MV), systems. Due to their potential advantages which are [1]:

- improved thermal comfort
- improved Indoor Air Quality (IAQ)
- reduced life cycle costs
- reduced floor to floor height in new constructions

In these type of ventilation systems, thermal buoyancy causes thermal stratification, resulting in higher temperatures at the ceiling level compared to the floor. Moreover, thermal buoyancy induces the fresh air from the lower part of the space to the breathing level, which causes to a much better inhaled air quality for occupants.

Due to the importance of UFAD systems, various aspects of them have been intensively investigated: Alajmi and El-Amer [2] investigated the energy performance of UFAD systems in commercial buildings for various inlet air temperatures. They reported that UFAD systems demonstrate significant amount of energy saving compared to MV systems. Jaakkola et al. [3] concluded that the ability to control temperature individually is an effective way to improve thermal comfort of occupants and decrease sick building syndrome (SBS) symptoms in UFAD systems.

Temperature gradient in vertical direction is one of the most important issues in occupants' thermal comfort conditions and it is likely for UFAD systems to reach an unacceptable value of temperature gradient in vertical direction.

In addition, vents position has great effects on the performance of UFAD systems. It seems like that UFAD systems with separate return and exhaust air vents can lead to a considerable energy consumption reduction [4].

At the present study, an UFAD system with combined and separate return and exhaust air vents was investigated for two common types of inlet diffusers;

Direct and Swirl. This study was performed in a populated space with 80 occupants (dense occupancy). In each of the indoor environments created by using these two common types of inlet diffusers, thermal comfort conditions of occupants, Indoor Air Quality (IAQ), and energy consumption reduction compared to the MV systems were predicted by changing the place of return air vent from ceiling to floor height.

METHODOLOGY

A large indoor space that is equipped by an UFAD system is used as the model space. This space is 10m length, 7.2 m width, and 4m height. Due to the symmetry, half of the model space in the Z axis direction should be simulated (Fig. 2). The conditioned cool air was delivered into the space through inlet diffusers located at the floor. The total air change rate is 0.73 m^3/s and the inlet air temperature is set equal to 21˚C. Fluorescent lamps were used to brighten up the room, and heat emitted by each lamp is 68 W. 40 occupants were simulated, and heat emitted by each occupant is 104.67 W. The northern, southern, western, floor, and ceiling walls are supposed to be insulated, and the eastern wall is supposed to be symmetry. It should be mentioned that the average static pressure in the exhaust air vent is supposed to be equal to the atmospheric pressure.

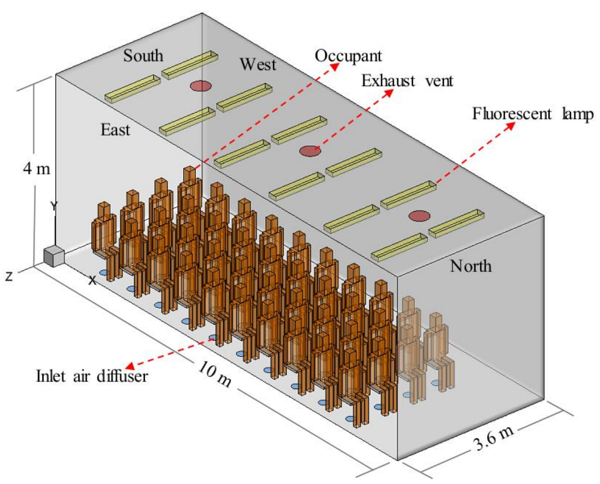

Fig. 2. Configuration of the model space with a symmetry wall

SIMULATION

A computer program, Airpak 2.0, has been used as the main simulating tool. This computer program is an accurate, quick, and easy-to-use design tool that simplifies the application of state-of-the-art airflow modeling technology to the design and analysis of ventilation systems which are required to deliver indoor air quality (IAQ), thermal comfort, health and safety, air conditioning, and/or contamination control solutions [5].

In this study, finite volume method with structured grid was used in solving procedure, and SIMPLE algorithm was used to resolve the pressure and velocity coupling.

CASE STUDIES DESCRIPTION

In this study, two common types of inlet diffusers (Direct and Swirl) were used in the model space. Effects of return air vent location on energy consumption reduction, occupants' thermal comfort conditions, and indoor air quality in the occupied zone were investigated for each of the inlet diffusers usage. Return air vent location from the floor height is set equally to the ceiling, 3.5, 2.8, 1.7, 0.8, and 0.1m for each case study, respectively. In each of the mentioned case studies, 80 percent of the inlet air is returned to the ventilation system through return air vent. Return air vent might be combined with the exhaust air vent (case study 1) or it might be separated (case studies 2, 3, 4, 5, and 6).

Thermal comfort Evaluation

PMV-PPD indices are used to survey the thermal comfort conditions of occupants in each case study. These indices were probed in the occupied zone, which is defined as the height of 1.7m from the floor. The PMV and PPD results for both of the inlet diffusers are presented in Fig. 3 and Fig. 4, respectively.

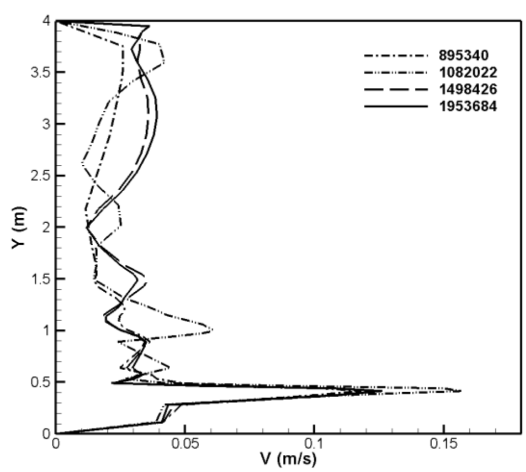

Fig. 3. Grid independency check for velocity along; x=4.0 and z= -1.3

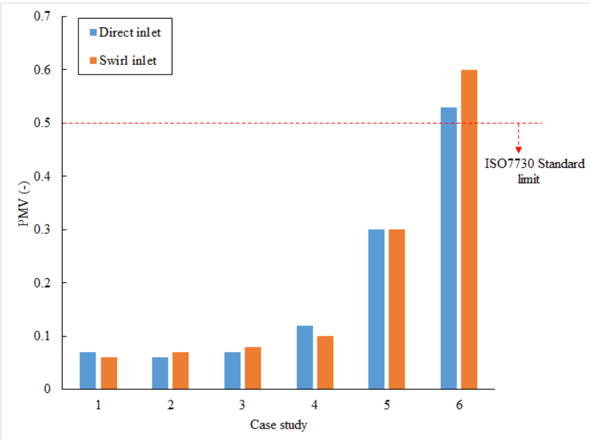

Fig. 4. PMV index for both of the inlet diffusers

Decreasing the return air vent location from ceiling to the floor height unfavorably affects the occupants general thermal comfort conditions, as indicated in Fig. 3 and Fig. 4.

When the swirl inlet diffuser is used, vertical air movement is very limited (see Fig. 5), and the diffuser discharge is relatively horizontal discharge compared to the time when the direct inlet diffuser is used (see Fig. 10(b)).

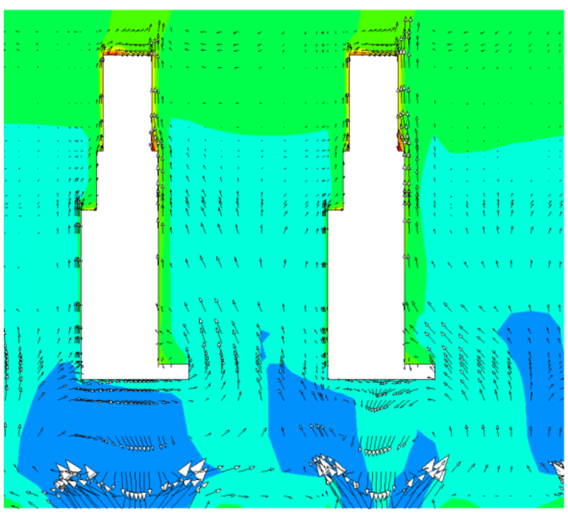

Fig. 5. PPD index for swirl inlet diffuser

By considering temperature distribution for both of the inlet diffusers, when the swirl inlet diffuser is used, the supply fresh air rapidly loses its momentum and spreads in a horizontal pattern along the floor due to gravity, so when the return air vent height is 0.8m and 0.1m (case study 5 and 6, respectively), there is a short-circuit of cold supply air and the PMV-PPD indices are the worst comparing to the other case studies.

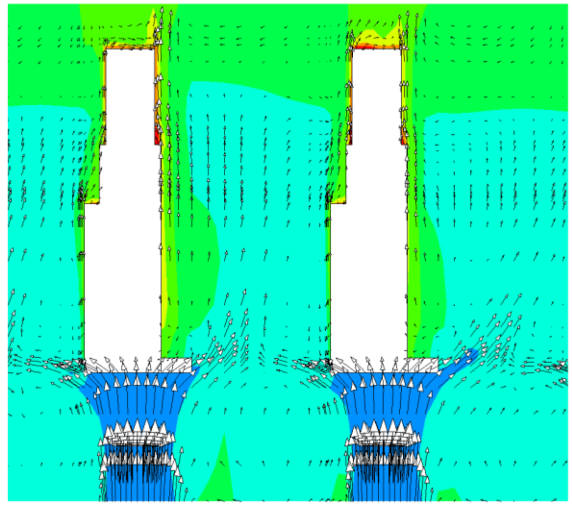

Fig. 6. PPD index for direct inlet diffuser

Case studies 1, 2, 3, and 4 are in the appropriate value of the PMV-PPD indices based on the ISO7730 standard suggestion, so they meet occupants' general thermal comfort needs.

LOCAL THERMAL DISCOMFORT EVALUATION

Temperature gradient in vertical direction is used as local thermal discomfort index. This index is evaluated between the head and ankles heights as a mean value, and the results are presented in Fig. 7 for both of the inlet diffusers.

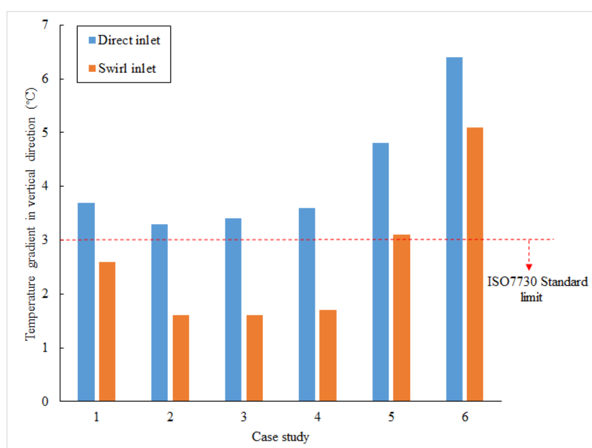

Fig. 7. Air distribution around seats and occupants for direct inlet diffuser

As presented in Fig. 7, there is a large temperature gradient in vertical direction by using direct inlet diffuser. This large temperature gradient in vertical direction is mostly because of the large vertical air movement of this type of diffusers. It cannot be overlooked that indoor environment obtained by the swirl inlet diffusers is more harmonized than the other one, and there is a small temperature gradient in vertical direction.

It should be noted that the temperature gradient in vertical direction for each case study is not in the maximum allowable range specified by ISO7730 standard by the direct inlet diffuser using, but by swirl inlet diffuser, case studies 1, 2, 3, and 4 are in the allowable range.

INDOOR AIR QUALITY (IAQ) EVALUATION

Mean local age of air is used for indoor air quality evaluation. This index is evaluated as a mean value at the height of 1.1m from floor which is defined as the breathing zone of the occupants. The results are summarized in Fig. 8.

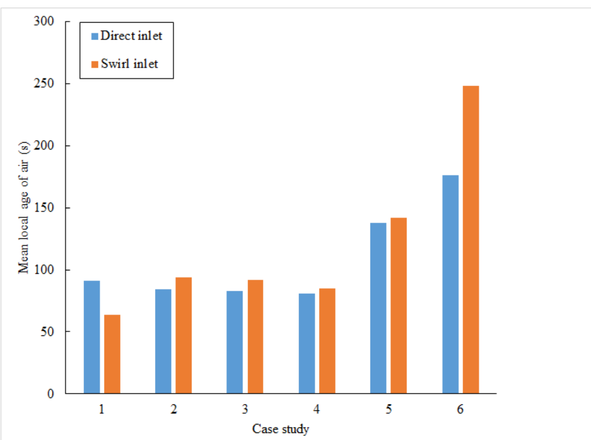

Fig. 8. Temperature gradient in vertical direction (°C) for both of the inlet diffusers

Mean local age of air index is reduced by reducing the return air vent position from ceiling (case study 1) to the upper boundary of the occupied zone (case study 4 or 1.7m). Then the mean local age of air index is increased by reducing the return air vent height from upper boundary of the occupied zone to the floor (case study 6). As mentioned earlier in case studies 5 and 6, some of the fresh air directly returns to the ventilation system without reaching to the breathing zone.

ENERGY USAGE REDUCTION

The value of $c_p \times \dot{m}_e \times (T_e - T_{set})$, which is the reduced cooling coil load in an UFAD system using rather than MV system using, is evaluated for each case study.

The value of energy consumption reduction is increased by reducing the height of return air vent. The largest value of energy consumption reduction is obtained in the lowest position of return air vent, yet for choosing a proper location for the return air vent, thermal comfort conditions of occupants, local thermal discomfort, and indoor air quality indices should be considered as determining factors. It should be noted that in direct inlet diffusers, energy consumption reduction is greater than swirl inlet diffusers (as presented in Fig. 9), although temperature gradient in vertical direction is not in the maximum allowable range.

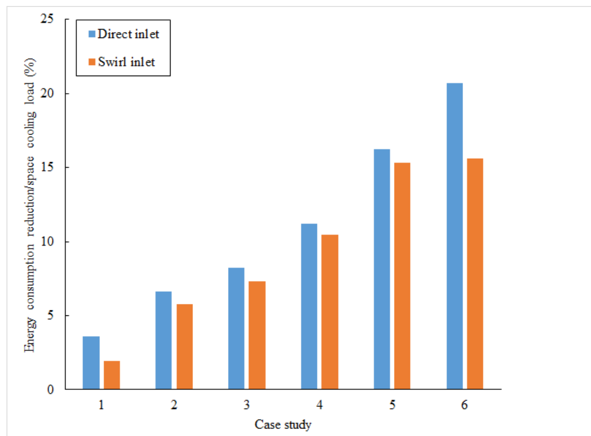

Fig. 9. Energy consumption reduction to space cooling load (%) for both of the inlet diffusers

CONCLUSIONS

In this study, the effects of combined and separate return and exhaust air vents on energy consumption reduction, thermal comfort conditions, and indoor air quality in an UFAD system were investigated for two common types of inlet diffusers; direct and swirl. Return air vent location from the floor height is set equally to 4.0, 3.5, 2.8, 1.7, 0.8, and 0.1m for each case study, respectively. Based on the results, the energy consumption reduction increases by reducing the height of return air vent from ceiling to floor height. Needless to say that considering energy consumption facet solely is not possible and thermal comfort conditions and indoor air quality should be examined. Therefore, PMV-PPD indices, temperature gradient in vertical direction, and draught risk as thermal comfort indices and mean local age of air as indoor air quality index were investigated. When the return air vent height is 0.8 and 0.1m, respectively, PMV-PPD indices and temperature gradient in vertical direction exceed the specified range of ISO7730 standard for both types of inlet diffusers. In direct inlet diffuser usage, temperature gradient in vertical direction in all of the case studies exceeds the allowable range.

Indoor air quality index reaches its best value at the upper boundary of the occupied zone for both of the inlet diffusers. It should be noted that, air flow did not reach local thermal discomfort levels for none of the investigated case studies, so opting a swirl inlet diffuser with the return air vent position at 1.7m from floor causes to the favorable results.

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