EXPERIMENTAL AND NUMERICAL STUDIES ON LOCAL HIGH EFFICIENCY AIR CONDITIONING SYSTEM FOR OFFICE BUILDINGS

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ABSTRACT
The effects of an air conditioning system for office buildings were studied experimentally and computationally. A displacement ventilation system was used as the main air-conditioning system, and a partition with a built-in circular fan was used to deliver the air-conditioned clean air near the floor supplied by the main displacement system to the occupant in the office directly. Experimental model tests and computational analysis that used the large eddy simulation (LES) have been carried out to obtain local air exchange efficiency, air temperature and air velocity distributions in a test chamber. The measured and simulated air velocities were compared. The results show that the partition's built-in circular fan has a great impact on the local air exchange efficiency in the immediate vicinity of the occupant. However, the thermal comfort of the occupant should be examined in more thoroughly.

INDEX TERMS
Displacement Ventilation, Air Exchange Efficiency, Model Test, Computational Analysis

INTRODUCTION
High-quality air can be provided for occupants in offices by supplying air-conditioned air directly to the breathing zone. However, if air supply terminal devices are installed near the occupants, the supply air temperature difference and supply air velocity should be low from the viewpoint of thermal comfort. Some previous studies of air-conditioning systems using a low-velocity air supply proposed a displacement ventilation system for office buildings (Sandberg et al. 1989, Chen et al. 1998). The displacement ventilation system can improve air exchange efficiency, however it often makes strong vertical air temperature stratification in the occupied zone that will cause thermal discomfort. To avoid this disadvantage, researchers suggested a cooling ceiling or fan coil device in conjunction with the displacement system to reduce vertical temperature differences by inducing a better mixing in the occupied zone (Fitzner 1996, Svensson 1989). The another approach is a task/ambient conditioning system, which used the underfloor air distribution to deliver conditioned air to the immediate vicinity of the occupant through floor grills, or in conjunction with the furniture and partitions (Tanabe 1994, Fisk 1991, Zhu 1995). However, in such studies, more than one air conditional device needs to be installed, making the total air conditional system more complicated. Therefore, the aim of this study is to develop an air conditioning system that can simultaneously improve the air exchange efficiency and thermal comfort. In this study, a new type of partition with a built-in circular fan was installed in a displacement ventilated test chamber to achieve mixing effects in the immediate vicinity of occupants. Model tests were carried out to examine air quality and thermal comfort of the test chamber by measuring local air

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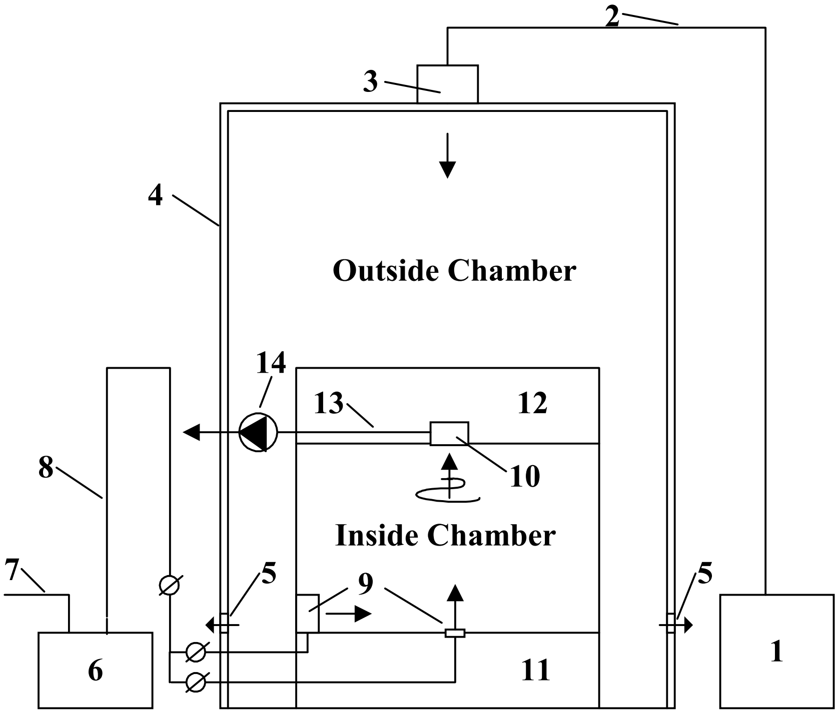


1: outside chamber air handling unit, 2: supply air duct, 3: air inlet, 4: adiabatic panel, 5: natural exhaust opening, 6: inside chamber air handling unit, 7: outdoor air duct, 8: supply air duct, 9: inside chamber air inlet, 10: inside chamber exhaust grille, 11: under floor chamber, 12: ceiling chamber, 13: exhaust air duct, 14: exhaust air fan

Figure 1. Schematic representation of the dual test chamber.

exchange efficiencies, air temperature profiles and air velocities in the chamber. Moreover, a computational analysis was performed to obtain the flow field of the test chamber. The experimental and computational results were compared to evaluate the performance of the proposed system.

TEST CHAMBER DESCRIPTION

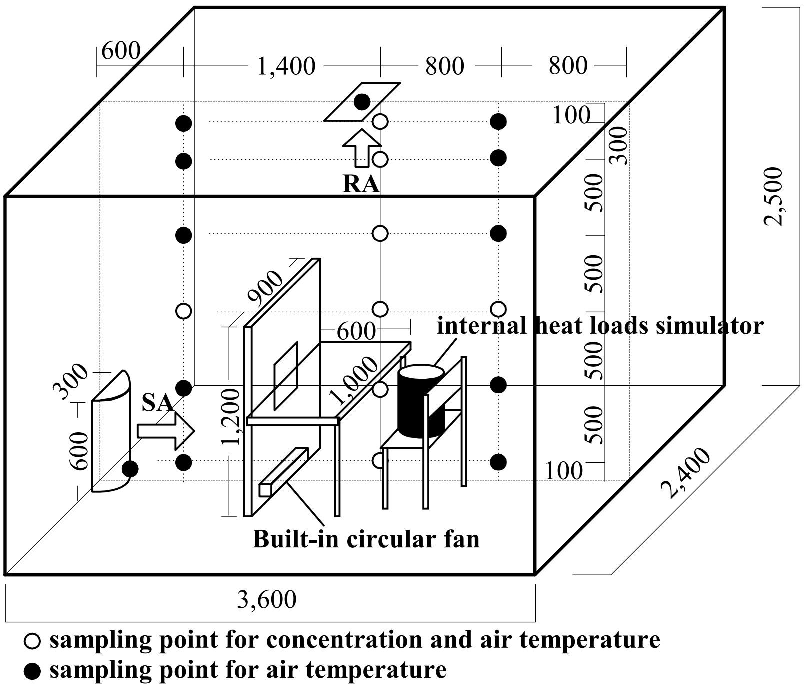
The chamber shown in Figure 1 is a dual test chamber located in SANKEN SETSUBI KOGYO CO., LTD. The volume of the outside chamber is equal to 5.0 x 3.6 x 8.0 m^3. The supply air was delivered from the diffuser mounted on the center of the ceiling and was exhausted from four exhaust openings located on the lower part of the walls. The inside chamber shown in Figure 2 was assumed to be an interior space of an office building. The dimensions are 3.6 m by 2.4 m with a ceiling height of 2.5 m. The supply air terminal of the displacement system is a semi-cylindrical wall unit installed on the floor. An exhaust grille was mounted in the center of the ceiling. A partition with a built-in circular fan, a desk and a chair were placed in the chamber. A cylindrical duct, painted black, with a light bulb inside was put on the chair to simulate the internal heat loads.

PARTITION WITH BUILT-IN CIRCULAR FAN

Figure 3 shows details of the partition. A circular fan, which was installed on the lower part of the partition, takes in fresh air near the floor and delivers it from a supply opening located on the opposite side of the partition below the desk. Furthermore, this partition is completely separated from the floor, therefore, it can be moved to change the layout of the office.

EXPERIMENTAL CASES

Table 1 lists the experimental cases and configuration. In all cases, the supply air flow rate was 100 m^3/h (supply air velocity was 0.12 m/s), and the internal heat loads were 200 W. Case 1 was performed with



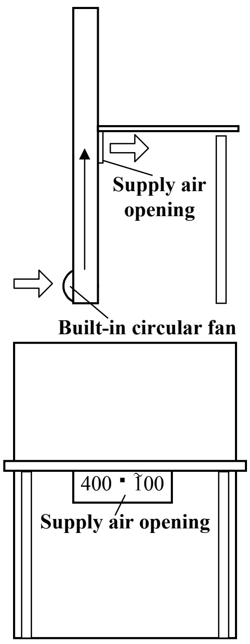


Figure 2. Layout of the inside chamber and experimental set-up, all measures in millimeters.

Figure 3. Partition and built-in fan.

Table 1. Experimental cases and parameters

Case	*Supply air flow rate [m³/h]*	*Internal heat loads [W]*	*Supply air temperature [ºC]*	*Circulated air flow rate by partition [m³/h]*
Case 1	100	200	23.8	-
Case 2	100	200	24.0	0
Case 3	100	200	21.0	20

no partition, and case 2 was tested with the partition, however the built-in fan was not used. The differences in the local air exchange efficiency and the vertical temperature distributions caused by the partition as an obstruction were evaluated by comparing these two cases. Case 3 was carried out using the partition. The circulated airflow volume using the built-in fan was kept at 20 m^3/h (supply air velocity was 0.57 m/s). The temperature of the outside chamber was maintained at 26 ºC. The temperature of the inside chamber 1.1 m above the floor was simultaneously kept at 26 degrees, which minimized the heat flow from the walls.

MEASUREMENT INSTRUMENTS AND PROCEDURES

All measurements were performed under steady-state room conditions. The local air exchange efficiency was measured in all cases. Sulphur hexafloride (SF6) was used as the tracer gas, and the tracer decay gas technique was used to determine the local air exchange efficiency at the sampling points in the chamber. SF6 was injected in the supply duct. The number of the sampling points was 8 in the chamber, 2 in the supply duct (before and after the injection point), and 1 in the exhaust duct. The concentrations of SF6 were continuously measured by a multi-gas monitor connected to the multipoint sampler and doser. The concentration data during the decay was then analyzed to determine the local age of the air at each sampling point. In this study, the local age of the air in the exhaust duct was considered as the nominal time constant of the chamber, and the local air exchange efficiency at each sampling point was calculated using the local age of the air at the same point and using the nominal time constant of the chamber. Furthermore, vertical air temperature distributions were obtained by using thermo couples with an interval of 2 minutes during the concentration measurements. A three-dimensional ultrasonic anemometer was used to carry out air velocity measurements in case 3 only. The measurement points were located in the vertical section in the center of the spanwise direction. The number of measurement points was 4 x 15 in the streamwise and vertical directions. Vertical direction traverse equipment was used to move the anemometer to the measurement point. The air velocities were measured at a sampling rate of 100 milliseconds. The number of samples taken at each point was 300. Then, the mean air velocities were calculated using the fluctuation data.

COMPUTATIONAL ANALYSIS

A large eddy simulation (LES), which can provide a detailed and accurate simulation of the turbulent flow, was used for the computational analysis. The Smagorinsky model was used as the subgrid-scale (SGS) stress model of the LES (Smagorinsky 1963). The Smagorinsky constant Cs was set to 0.16 and was modified by the Van Driest dumping function to account for near-wall effects. The indoor space of the test chamber model used as the computational domain was the same as that in the experiment. The variables in the numerical analysis were stored on a staggered mesh. The Piacsek-Williams scheme was used for the convective term, and a second-order centered differential scheme was applied for the other spatial derivatives. The time marching scheme was the Adams-Bashforth scheme. A two-layer model (Werner & Wengle 1991) was used for the boundary conditions at the solid walls. The time interval of analysis was 10^{-3} seconds. The computation was first carried out for 500 seconds. The simulation then continued, and statistics were collected during 500 second periods.

RESULTS AND DISCUSSION

Figure 4 shows comparisons of the vertical profiles of the air temperature and the local air exchange efficiency for cases 1 and 2 at the center of the chamber. The differences in the air temperature between them were small. However, the local air exchange efficiency in case 2 at the center of the chamber, especially in the lower part, behind the partition, was noticeably lower then that in case 1. These differences in local air exchange indicated that the fresh air brought by the DV supply terminal was hampered by the arrangement of the partition set in this study. Figure 5 shows the vertical profiles of air temperature and local air exchange efficiency at the center of the chamber, which were measured when the built-in fan was operated or not. In this figure, the local air exchange efficiency was increased by operating the built-in fan. The maximum value was over 2.0. Thus, the supplied fresh air from the DV supply terminal was delivered by the built-in circular fan before settling in the lower part of the chamber. However, the vertical air temperature difference between 0.1 and 1.1 m was increased by a value of 2 degree when the built-in fan was not used. The mean velocity vectors obtained by computational analysis for case 3 in the vertical section at the center of the spanwise are shown in Figure 6. The air brought from the DV supply terminal was delivered toward the floor and inhaled by the inlet of the partition. The air current from the supply opening of the partition, along the underside of the desk, reached the internal heat loads simulator on the chair and then combined with the thermal plume flow by the simulator. The combined air current reached the ceiling and separated into two parts along it in opposite directions. Figure 7 compares the vertical profiles of the mean velocity in the streamwise direction. The profiles were measured by experiment and calculated using computational analysis. The computational and experimental results were similar, while at locations x = 320 mm and x = 2100 mm, discrepancies were observed near the peak points. These discrepancies were probably due to the inflow boundary of the computational analysis, which replaced the supply air velocity with the air velocity measured in the near zone of the DV supply unit. This replacement was due to the difficulty in measuring an accurate value of the velocity at the semi- cylindrical surface of the DV supply unit. The figure also shows the maximum air velocity at the location x = 2100 mm in the near zone of the occupant. The maximum air velocity reached a value of 0.6 m/s, which may cause some complaints about thermal comfort. Therefore, the location and air rate for the supply opening of the partition should be examined more thoroughly.

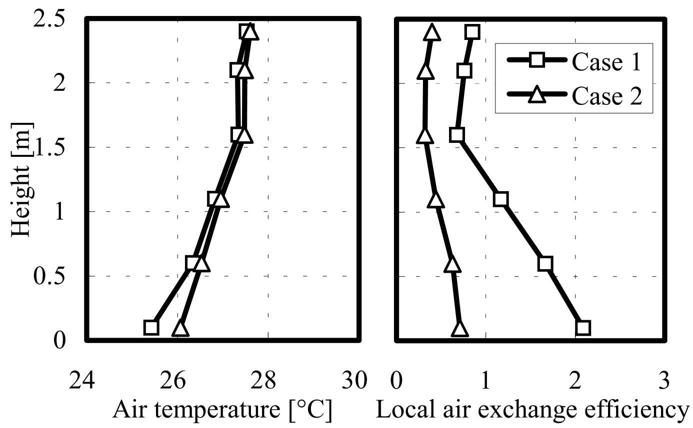


Figure 4. Comparison of vertical profiles of air temperature and local air exchange efficiency at center of test chamber for case 1 and case 2.

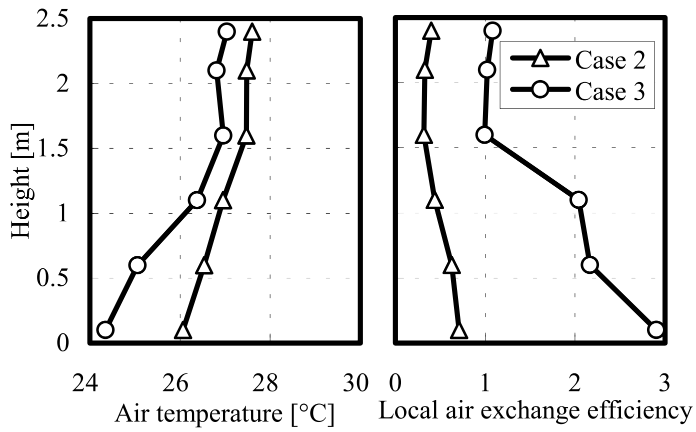


Figure 5. Comparison of vertical profiles of air temperature and local air exchange efficiency at center of test chamber for case 2 and case 3.

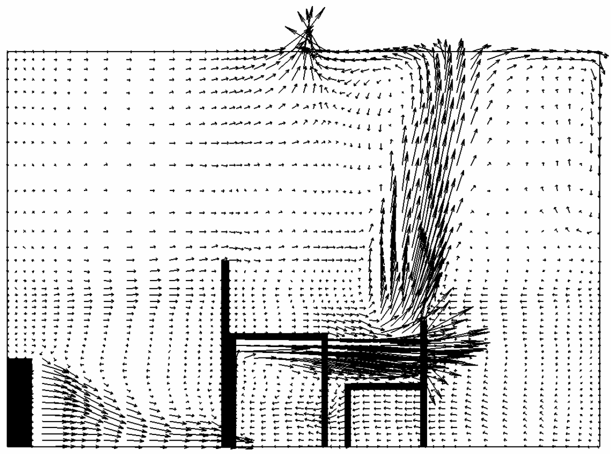


Figure 6. Mean velocity vectors by computational analysis for case 3

CONCLUSION

A new type of partition was developed with a built-in circular fan, which improve the local air exchange efficiency in its occupied zones, due to the better mixing of the indoor air delivered from the displacement ventilation system for office buildings. Model experiments and computational analysis were used to evaluate the performance of this system. As a general conclusion, office partitions appear to have

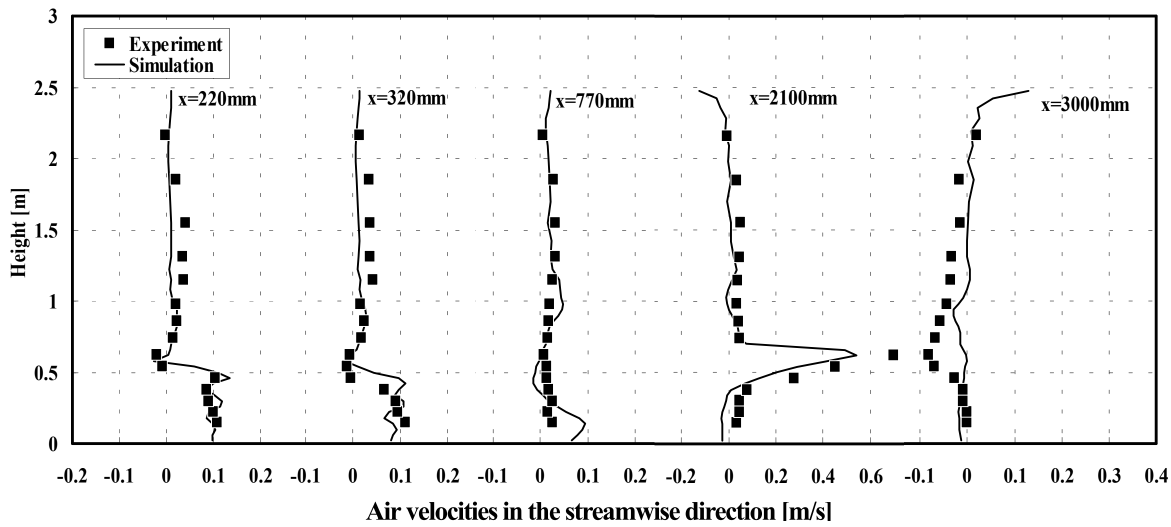


Figure 7. Comparison between measured and simulated air velocities for case 3

great influence on the local exchange efficiency in the occupied zone, depending on the office configuration (floor area, ceiling height, etc.) and the location of the partition. The local air exchange efficiency in the near zone of the occupant was improved when a circular fan was built into the partition. However, we noticed that the vertical air temperature differences and the value of the air velocity obtained were increased. The location and area of the supply opening and the supply air velocity of the partition should be further examined so as to ensure the thermal comfort of the occupant.

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