Deflection ventilation—a conceptual introduction

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ABSTRACT

This paper proposes a new mode of ventilation for indoor airflow. It uses a plate or a curved vane to divert a jet of air directly into the breathing zone. Computational results show that with properly selected diffuser locations and design air supply velocities, the proposed system would be able to maintain better thermal comfort with a smaller temperature difference between the head and foot level, and possibly lower energy consumption, when compared with conventional systems. This type of ventilation system has the potential to achieve better indoor air quality (IAQ) in the breathing zone but further work is required to determine if the IAQ benefits would be significant.

INDEX TERMS

Ventilation mode; Deflection ventilation; IAQ; Thermal comfort; Energy efficiency

INTRODUCTION

Conventional ventilation modes applied in an air-conditioned non-industrial indoor space are broadly categorized into two groups, namely: mixing ventilation and displacement ventilation. Task ventilation is also another type of ventilation but is less common.

Mixing ventilation is a traditional mode of ventilation and is still widely used today. It can take care of both heating and cooling with highly varying load patterns. The mixing is achieved by supplying the ventilation air as a high velocity jet to entrain the air already in the room. Mixing ventilation could provide comparably unique air temperature distribution in the occupied zone. However, it can also lead to problems, such as poor IAQ, air draft in the occupied zone and some other thermal discomfort. In addition, it normally consumes more energy than displacement ventilation.

Displacement ventilation has been used quite commonly in Scandinavia during the past 20 years as a means of ventilation in industrial facilities to provide better IAQ and to save energy. More recently, its use has been extended to ventilation of offices, classrooms, commercial buildings and other non-industrial premises. In contrast to mixing ventilation, buoyancy forces (induced by heat sources) govern the airflow in displacement ventilation. Because the airflow is thermally driven, this mode of ventilation functions satisfactorily only when excessive heat is to be removed. In a room ventilated by displacement, the air quality in the breathing zone is usually better than in a mixing system operated with the same airflow rate. Additionally, the ventilation efficiency of a displacement-ventilated room is also significantly better than that of the mixing ventilated room (Awbi, 1991). However, there are more severe restrictions due to thermal discomfort in a displacement system than in a mixing system. ISO 7730 recommends a maximum air temperature gradient of 3 K between 1.1 and

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0.1 m above the floor (ISO 7730 1984), which corresponds to a percentage dissatisfied of 5%. However, the ASHRAE Standard recommends the same temperature gradient between 1.7 and 0.1 m above the floor (ASHRAE, 1992), relative to a standing person. Otherwise, it will cause thermal discomfort. Therefore, supply air temperature and airflow rate must be carefully studied to assure proper temperature distribution and velocity distribution. Often a displacement ventilation system cools the lower part of a space too much, where no heat source is normally located, resulting in discomfort and energy waste.

Where the IAQ of the breathing zone and energy efficiency are concerned, the most effective system is task ventilation. It may be used to remove excessive cooling load and to maintain a comfortable indoor environment. Task ventilation systems supply air through nozzles located near occupants (e.g. at an edge of a desk). Potential draft exists because of the short distance between the supply gears and the occupants. A field study found that workers in a task-ventilated office were satisfied with the thermal conditions because they could individually control the local environment (Bauman *et al*., 1993). The occupants can control the temperature, flow rate and direction of air from the nozzles. The measurements conducted by Faulkner *et al*. (1993, 1995) showed that the ageing of air at the breathing level with task ventilation was approximately 30% less than that with mixing ventilation. However, application of task ventilation depends much on indoor furnishings. For example, sometimes it is difficult to use nozzles and connect ducts in various indoor spaces. Additionally, some occupants in certain spaces do not normally stay in a fixed position, e.g. the situation in a retail shop. These limit the use of task ventilation.

DEVELOPMENT OF THE CONCEPT OF DEFLECTION VENTILATION

Mixing ventilation, displacement ventilation plus task ventilation all have their limitations. To overcome these problems, a new ventilation mode is proposed. The new mode should be able to provide good IAQ in the breathing zone, to have minimum temperature difference between head and ankle levels, to obtain thermal comfort in the occupied zone, to use ducts and diffusers conveniently and to have high energy efficiency.

The underlying principle of displacement ventilation implies that in an air-conditioned room, the conditions of IAQ and thermal comfort beyond the occupied zone (say $H > 2$ m) are of little interest. By the same token, the IAQ beneath the breathing zone (say $H < 0.8$ m) is less important unless the occupants are expected to be very young children. Ventilation efficiency would be maximized if air is supplied directly into the breathing zone, and the air forms a well controlled 'fresher air layer' to fill the breathing zone. The thickness of the fresher air layer depends on the nature of occupancy. At the same time, a quasi-stagnant zone is also formed between the breathing zone and the floor (say $0 < H < 0.8$ m). The temperature within the quasi-stagnant zone should be reasonably controlled.

The proposed deflection ventilation creates an air-jet, directed upwards from the floor or downwards from the ceiling. A plate or curved vane is then set at an appropriate place to divert the air-jet. When the vertical air-jet meets the plate or curved vane, it turns horizontally and forms a horizontal layer of air. Therefore, the air age of the air layer should be less. It brings fresher air to the breathing zone than that of conventional modes of ventilation. Indoor air should mix well and the air temperature gradient should be low so as not to cause thermal discomfort. Because air is supplied directly to the breathing zone, less fresh air bypasses occupants. Thus, there are also possibilities to reduce fresh airflow rate for energy saving.

METHODOLOGY

The new concept of deflection ventilation needs to be tested. Two main approaches are available for the study of airflow and pollutant transport in buildings: experimental investigation and computer simulation. Direct measurements give the most realistic information but are expensive and time consuming. The purpose of the research at the first stage was to find out whether the new ventilation mode is feasible. A Computational Fluid Dynamics (CFD) technique was applied. Due to limited computer power and capacity available at present, turbulence models have to be used in the CFD technique in order to solve flow motion. The use of turbulence models leads to uncertainties in the computational results because the models are not universal. Therefore, it is essential to validate a CFD program by experimental data (Yuan *et al*., 1999).

A CFD model based on the re-normalised group k–ε model and the wall function was used for simulation (Lin *et al*., 1999). Validated for both mixing ventilation and displacement ventilation, the model has been tested for hundreds of cases, including offices, classrooms, shops and workshops with supply air upwards and downwards. Simulation results agree well with experimental results. The flow characteristics between displacement ventilation and mixing ventilation are similar—both have strong pressure and buoyancy driven flows (Yuan *et al*., 1998). The condition of deflection ventilation was expected to be between those of mixing ventilation and displacement ventilation based on identical internal layout and similar boundary conditions.

A commercial CFD code CFX was used for the computations. By default, the code uses the finite-volume method and the upwind-difference-scheme for the convection term (AEA, 1999).

TEST CASES

Figure 1 shows a small office for testing. The dimensions of the room are 4 m × 3 m × 2.7 m, with only one occupant inside. Heat fluxes ingress through the west wall ($x = 0$). Conditioned air is supplied from the opening A1 on ceiling, with a curved vane or plate below. In the computation, both curved vane and plate will be simulated, and the plate can be horizontal or oblique. The opening B1 is the exhaust.

The whole computational domain, the space of the room, needs to be divided into a number of finite volumes by a grid system. The flow variables, such as velocity, temperature and concentration, are solved at the centre of each finite volume. The finer the grid is, the more accurate the results will be. However, a fine grid will cost more computing time and capacity. A 48 × 44 × 24 grid was deemed accurate enough; little improvement in accuracy will be achieved even if finer grids be employed (Yuan *et al*., 1999). For the present study, the computational domain is divided into a 40 × 30 × 27 grid.

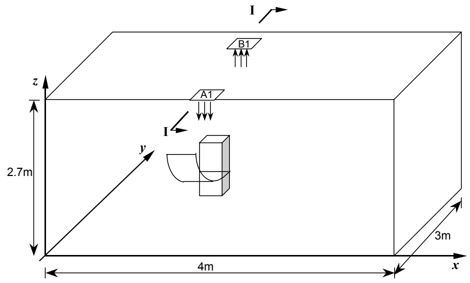
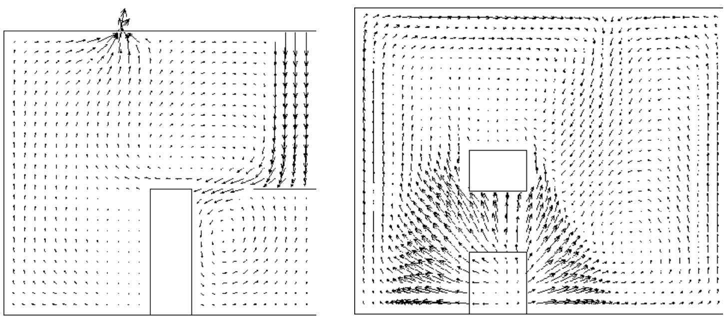


Figure 1 Sketch of the model office.

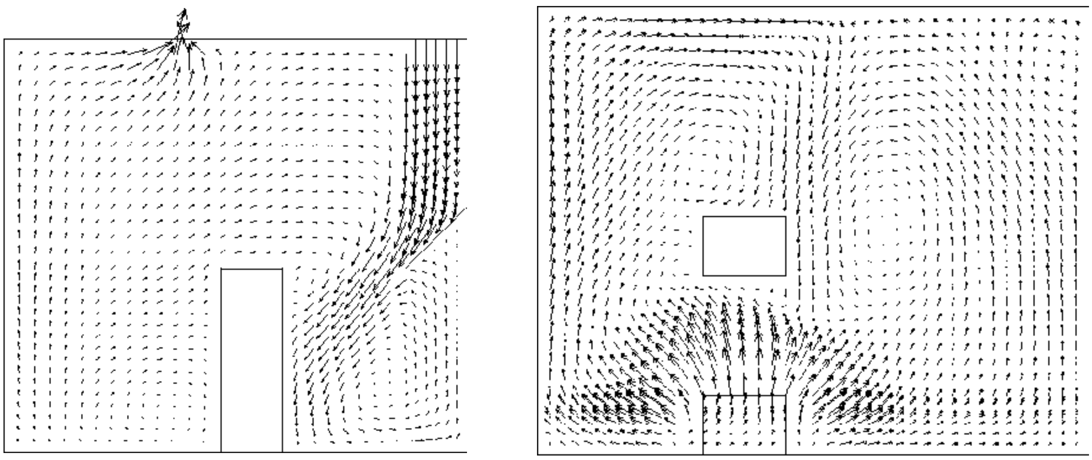
RESULTS

The velocity of supplied airflow from the ceiling opening was set to be 6.0 m/s uniformly in the three cases. Supplied air temperature was 16°C. Figures 2–4 show the computed velocity profiles at Section I-I ($x = 1.6$ m) and at breathing level $z = 1.1$ m, with a horizontal plate, oblique plate and curved vane to divert the air jet, respectively.



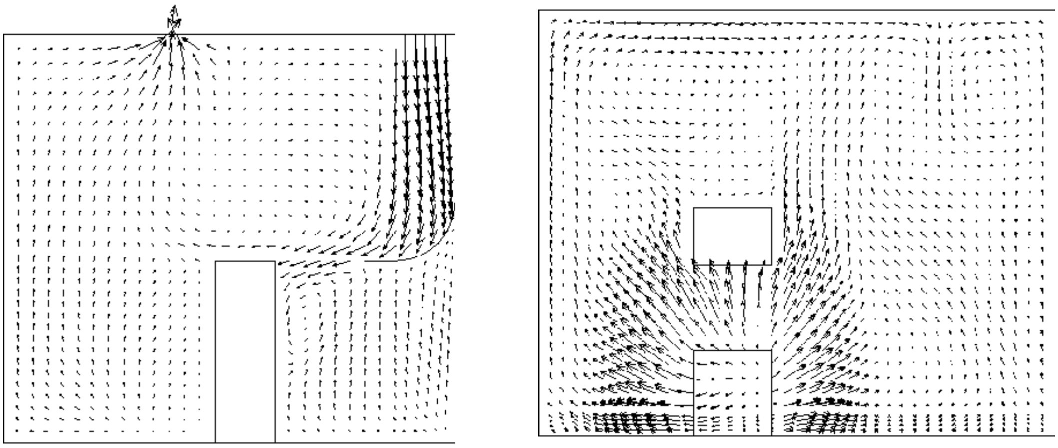
(a) (b)

Figure 2 Velocity profile with horizontal plate: (a) section I-I; (b) at breathing height.



(a) (b)

Figure 3 Velocity profile with oblique plate: (a) section I-I; (b) at breathing height.



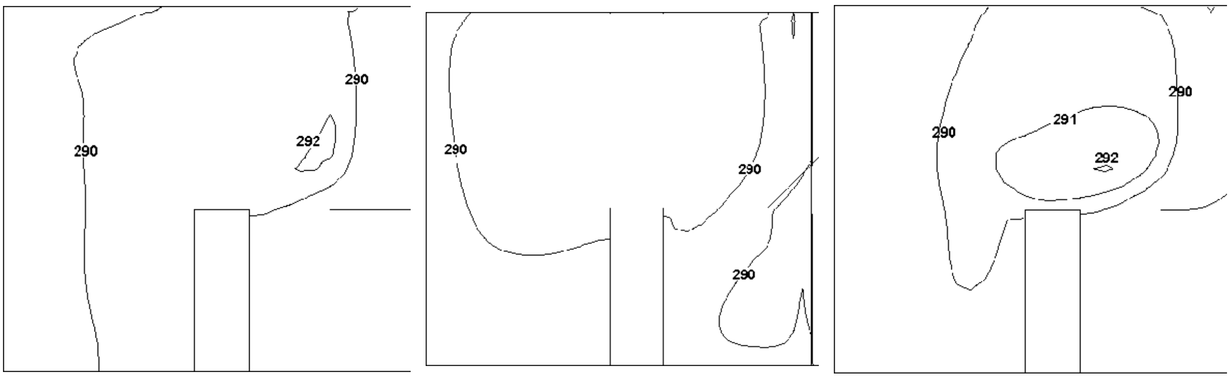
(a) (b)

Figure 4 Velocity profile with curved vane: (a) section I-Il; (b) at breathing height.

Figure 2(a) shows that the downward air-jet is diverted to form an almost horizontal flow by the plate and flows towards the occupant with a little slope. When it meets the occupant, it turns around and forms an eddy. Figure 4(a) shows similar result with less slope and smaller eddy when a curved vane was used. But the flow with an oblique plate (Figure 3) is different. When the air-jet hits the oblique plate, it flows along the direction of the plate and follows the direction even after it leaves the plate.

Part (b) of Figures 2–4 are velocity profiles at the breathing zone. The figures show that when the air-jet hits the plate or vane, the velocity changes from vertical to horizontal and the air flows in all directions around the plate. The length and width of the plate affect air velocity and direction to a certain extent.

Except the zone near the diverting plate or vane, the velocity distribution in other occupied zones is comparatively unique. Air mixed well in the zone so that the indoor air temperature is comparatively uniform, as shown in Figure 5. The temperature difference between the head and angle level is minimized so as not to cause such thermal discomfort as that of displacement ventilation.



(a) (b) (c)

Figure 5 Temperature profile of the three cases (K): (a) with horizontal plate; (b) with oblique plate; (c) with oblique plate.

CONCLUSION AND RECOMMENDATIONS

Deflection ventilation is proposed as a new ventilation mode to improve IAQ in the breathing zone, thermal comfort in the occupied zone as well as energy efficiency. A CFD program with the re-normalized group k–ε model of turbulence has been used to test the new scheme.

- The supply air jet was diverted to the breathing zone by a plate or vane. However, the diverted air-jet may not necessarily flow horizontally under any circumstances even guided with a horizontal plate or a vane. The direction could be oblique upwards or downwards. An optimal angle must, therefore, be found to divert supply air into the breathing zone through proper design of air volume, angle of the guide plate or the vane, and so on. The air supply outlet should also be strategically positioned.
- Different types of vanes lead to different results. An oblique plate should be installed at a proper place higher than the breathing zone. It can be stipulated that installation is not allowed within the occupied zone in the rooms.
- This kind of ventilation can be used both in all-air systems and in primary air plus fan coil system, especially for distributing primary air only.

Preliminary results show that deflection ventilation provides quality air in the breathing zone and thermal comfort in the occupied zone. Further experimental, theoretical and numerical studies on the proposed ventilation mode are needed, including tests of more cases under various internal and boundary conditions. Optimal design conditions for deflection ventilation are to be found and design guidelines are to be formulated.

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