Stratum Ventilation for a Retrofitted Classroom

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ABSTRACT

There is worldwide plea to reduce carbon emission. Several governments in East Asia recently have responded by setting higher indoor temperatures in summer. But the public need to be convinced that such practice would not sacrifice indoor environmental quality, especially thermal comfort of the occupants. To implement such a measure, suitable ventilation system(s) to work under the unconventional conditions should be identified.

Stratum ventilation, a new mode, is proposed for the elevated indoor temperature. The purpose of the research was to find out whether the new ventilation mode is feasible for the warm condition. A stratum ventilation system is installed for an experimental classroom. Experimental investigation and/or computational fluid dynamics simulation are used for the study of airflow and pollutant transport in the room. Various factors including percentage dissatisfied (PD/DR) and mean air age are calculated to determine the performance of the ventilation system. Results show that for the classroom, the system is able to provide air of young age without the penalty of over-cooling lower part of a room, to maintain thermal comfort with a smaller temperature difference between the head and foot level, lower energy consumption, and better indoor air quality (IAQ) in the breathing zone.

KEYWORDS

Elevated indoor temperature (warm condition), stratum ventilation, flow pattern, indoor air quality (IAQ), thermal comfort, classroom.

INTRODUCTION

The earth is already showing many signs of worldwide climate change. Minimizing the energy consumption by air conditioning systems would help to reduce CO_2 emission. For this purpose, revised EN ISO 7730 adopted Fountain and Arens' (1993) theory that higher air speed was required to offset increased indoor temperature. Proactive actions in this regard have been taken by several governments in East Asia. The Electrical and Mechanical Services Department (EMSD) of Hong Kong S.A.R. drew up clear guidelines that ideal temperature of an air-conditioned space in summer was set to 25.5°C. The National Development and Reform Commission (NDRC) of the Chinese State Council issued similar guidelines to set the indoor temperature to 26°C in the cooling season. The room temperature in the "Office of President" in Taipei has been set to 27°C after Mr. Ma Ying-jeou's inauguration in May 2008 (NOW news 2008). In a more radical move, the Ministry of the Environment (MoE 2005) of Japan has been encouraging people to set the temperature of air conditioners at offices to 28°C during the summer months.

The aforementioned administrative measures seem to be in line with the principle of sustainable development. But at least two questions still remain:

1. Would such practices deteriorate indoor environmental quality, especially thermal comfort? and
2. Are suitable ventilation system(s) available for the elevated indoor temperature settings?

To answer the first question, various studies were carried out to investigate the feasibility of a higher indoor temperature setting. Zhang et al (2007) found that in neutral to warm conditions, dissatisfaction with too little air movement is common. With an air speed of 1 m/s in the breathing zone at warm temperatures, the air movement was judged acceptable. In contrast, still air was not acceptable in warm environments (Zhang et al 2008). A number of laboratory and field studies found that air movement compensated for warm temperatures in making people comfortable, and recommended high air movement levels for summer conditions (Fountain 1991, Mayer 1992, Fountain et al 1994, Arens 1998, Toftum 2004). All these conditions deviate from the traditional thermal comfort standards for summer. The side directions of an occupant are known to be considerably less sensitive to air movement (Toftum 1997), and maybe also the front directions (Mayer 1992). The higher air movement could disrupt the thermal plume (velocity typically at 0.15 m/s) around an occupant’s body, and thereby improves an occupant’s perceived air quality, because the thermal plume transports pollutants from the floor and the body surface up to the breathing zone. Providing air movement indoors is typically much more energy-efficient than providing additional air conditioning (Arens 2007). Relaxing the current draft limit for neutral-to-warm conditions (above 23ºC) would open up opportunities for saving energy that are now only restricted to personally-controlled air movement devices. There might be a range of temperatures and air velocities in which devices that move air across large areas could do so without creating an appreciable draft risk for the occupants (Arens 2007).

To sum up the aforementioned literature, a suitable ventilation system should be identified. In an occupied zone, the system should be able to provide comparably higher temperatures and air movements which are still within the reasonable ranges as advised in the literature. Horizontal airflow(s) from the side and/or front direction(s) of occupant(s) are preferred.

To answer the second question in the previous section, the existing ventilation modes should be screened. The conventional ventilation modes applied to an air-conditioned indoor space can be broadly categorized into three categories, namely: mixing ventilation, displacement ventilation and task/personalized ventilation.

Mixing ventilation is a traditional ventilation mode and is still widely used today. Its ceiling-mounted air supply inlets result in:

1. horizontal air supply not being available, and
2. significant fan energy consumption due to the high air circulation that is necessary for the required air movement in the occupied zone.

It also leads to problems such as normally poorer IAQ and higher energy consumption as compared with displacement ventilation.

In a room with displacement ventilation, air quality in the breathing zone is usually better than that in a room with mixing ventilation operated with the same airflow rate.

Additionally, ventilation efficiency of a displacement-ventilated room is also significantly better than that of a mixing-ventilated room (Awbi 1991). However, because the airflow of displacement ventilation is thermally driven, using horizontal air movement is against the working mechanism of displacement ventilation. Wyon and Sandberg (1990) found that a displacement ventilation system usually cooled the floor part of a space, where no heat source exists, excessively, resulting in discomfort and energy waste.

As far as the IAQ of breathing zone and the energy efficiency are concerned, task/ personalized ventilation is the most effective. It also satisfies the requirements summarized at the beginning of this page. Task/personalized ventilation systems supply air through nozzles located near occupants. It is often difficult and/or expensive to equip nozzles and to connect ducts in various indoor spaces, especially to keep up with the paces of re-partitioning. On the other hand, some occupants in certain spaces do not normally stay in a fixed position, e.g., the situation in a retail shop. These problems limit the application of task/personalized ventilation.

Stratum ventilation, a concept developed by the authors in recent years, also satisfies the summarized requirements (Lin et al 2005a). Stratum ventilation works by placing supply inlets at the side-wall of the room just above the height of the occupants, sedentary or standing depending on nature of occupancy. The fresh air enters the room and then gradually loses momentum further away from the supply. The fresh air supply is sufficiently strong to provide adequate fresh air. The range of velocity and the locations of air supply should be carefully optimized to break the boundary layer around the occupant(s) and to minimize risks of draft. The thickness of the fresher air layer required depends on the nature of occupancy. At the same time, a quasi-stagnant zone is also form between the breathing zone and the floor (say $0 < H < 0.8$ m). The temperature within the quasi-stagnant zone should be reasonably controlled. Indoor air should mix well and air temperature gradient should be low hence not to cause thermal discomfort. Because air is supplied directly to breathing zone, less fresh air bypasses occupants. Thus there are also possibilities to reduce fresh airflow rate for energy saving. Also because air is supplied directly to the occupied zone, the supply air temperature should usually above 18ºC. This implies that the evaporating temperature of the refrigeration plant can be elevated accordingly, which would result in higher coefficient of performance (COP) of the refrigeration plant. Shown in Figure 1 is the conceptual diagram of stratum ventilation. Stratum ventilation is proposed to cope for elevated indoor temperature.

METHODS

The purpose of the research was to find out whether stratum ventilation is feasible for the new conditions of higher room temperature and air movement. 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. Several experimental trials of exploratory nature are conducted.

Computational Fluid Dynamics (CFD) technique is also 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 wall function was used for simulation (Lin et al 2005b). Validated for both mixing ventilation and displacement ventilation, the model has been tested for hundreds of cases, including offices, classrooms, shops and workshops with air supplied upwards and downwards. The condition of stratum ventilation is found to be between those of mixing ventilation and displacement ventilation based on identical internal layout and similar boundary conditions. The model was also validated recently for stratum ventilation with air supplied horizontally (Lin et al 2006). Experimental investigation into the entire classroom is not available at the meantime. Only a room shown in Figure 2 is tested. The results obtained (Figures 3 to 5) are also used to further validate the CFD model. 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 Technology 2000).

TEST CASE

Limited by the length, only a case study is presented as an example to demonstrate the performance of stratum ventilation for the warm condition. Air velocity and percentage of dissatisfied people due to draft (PD) (Fanger and Christensen 1986, ISO 7730) and the mean local air age are used as the evaluation criteria. All these parameters are determined by the thermal and flow boundary conditions, such as the size and geometry of the space, rates and temperatures of airflows and heat sources.

An existing classroom is retrofitted to adapt for stratum ventilation. The classroom layout is shown in Figure 6. The major parameters are shown in Table 1. The classroom is supplied by 4 supply inlets located at the east wall, and also by another 4 supply inlets at the west wall. There are a total of 16 occupants in the classroom.

RESULTS AND DISCUSSION

Airflow Pattern

The air initially enters the room and forms a small layer of fresh air directly to the occupants as shown in Figure 7. Close to the supply inlet the velocity is dominated by the momentum from the supply, producing this stratum effect. Further from the supply a combination of the convection and the impulse from the supply results. Obviously further from the supply the more the convection effects become more dominant. However, in the occupied zone the supply air drops down gradually, flows across the room. Then as it enters the centre of the room, it is picked up via convection and delivered to the breathing zone.

TABLE 1: Major parameters for typical classroom

No. of person	Lamp [W]	PC [W]	Air circulation [m^3/s]	Fresh air intake [l/person/s]
16	120 × 18	70 × 9	0.3	10

Predicted Dissatisfied (PD)

The PD levels due to draft are calculated, Figures 8. The draft effect is dominated by convection; the values are at around 10% or less, though the peak value is 40% at the supply inlets. The PD value at the chest level is found to be better than that at ankle level.

Temperature Distribution

The temperature distribution is shown in Figures 9. Two effects are observed in the classroom under stratum ventilation. The first effect is observed near the supply inlets where the temperature is lower. Temperature stratification is obvious.

Air Age

Shown in Figure 10, local mean air age is used as a measure of ventilation effectiveness. The levels are generally between 200 and 350 s in the breathing zone. The supply air does not reach halfway into the room resulting in variant air ages in the breathing zone. Further into the room, the air ages are less dominated by the supply momentum. Stratification in air age is also significant.

CONCLUSIONS

Through the case study, under warm conditions, stratum ventilation has shown to be effective in providing satisfactory indoor air quality and thermal comfort. The computed PD levels are good in the occupied zone of the classroom. The system demonstrates that it is able to vent effectively without the penalty of over-cooling lower part of the room. The results indicate that there is potential for this type of system. The research into stratum ventilation is still in its early stage. Further research is needed to investigate the effects of the different parameters such as temperature, air velocity and locations of supply to determine the optimal configuration for this type of ventilation system.

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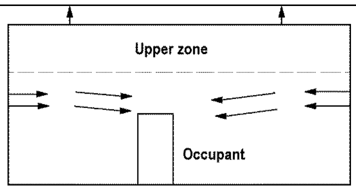

Figure 1: Conceptual diagram of stratum ventilation

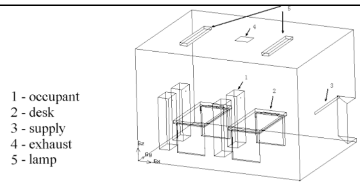

Figure 2 : Experimental layout

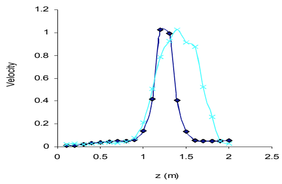

Figure 3 : Measured and computed velocities

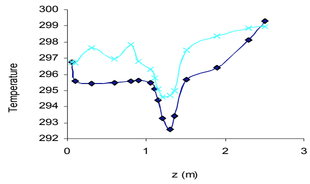

Figure 4 : Measured and computed temperatures

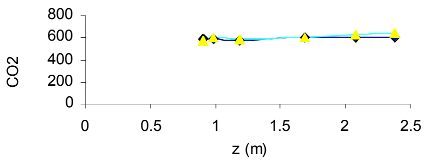

Figure 5 : Measured and computed CO_2 levels

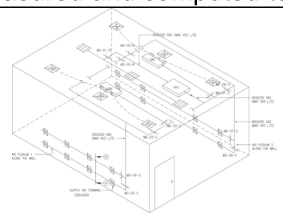

Figure 6 : Isometric view of classroom

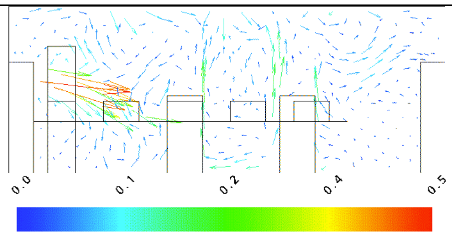

Figure 7 : Computed airflow pattern (m/s)

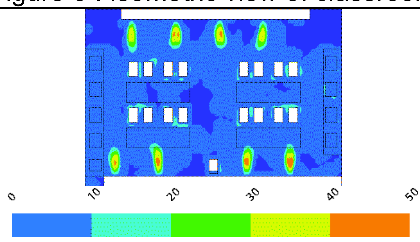

Figure 8 : PD index (%)

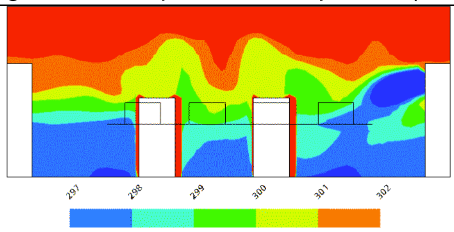

Figure 9 : Computed temperatures (K)

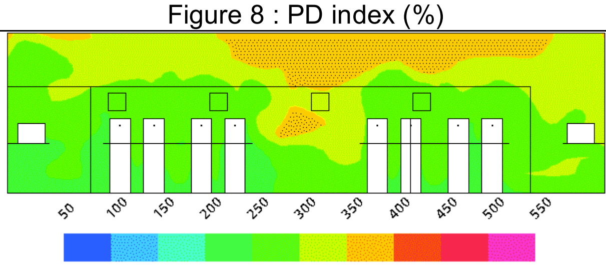

Figure 10 : Computed air ages (s)