THE INFLUENCE OF AIR SUPPLY AND EXHAUST LOCATIONS ON VENTILATION EFFICIENCY AND CONTAMINANT EXPOSURES IN ROOMS

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ABSTRACT

An efficient ventilation system is characterised by a well-organised and turbulence-controlled air stream that rapidly corrects disturbances in air quality and thermal comfort in the ventilated space. Air supply and exhaust conditions are investigated here in order to find stable flow conditions and an efficient elimination of both gas and solid phase contaminants. Heat and thermal comfort requirements are also included. Existing displacement ventilation installations cannot always meet the current requirements of good indoor air quality, thermal comfort and energy use, and improved solutions are therefore needed. It is shown here that the conditions of both air supply and exhaust are critical to the overall ventilation effectiveness in a room. Personal exposures have been studied by computer simulations. A new numerical method has enabled assessments of exposures to particle contaminants, which are extremely difficult to measure in practice.

INTRODUCTION

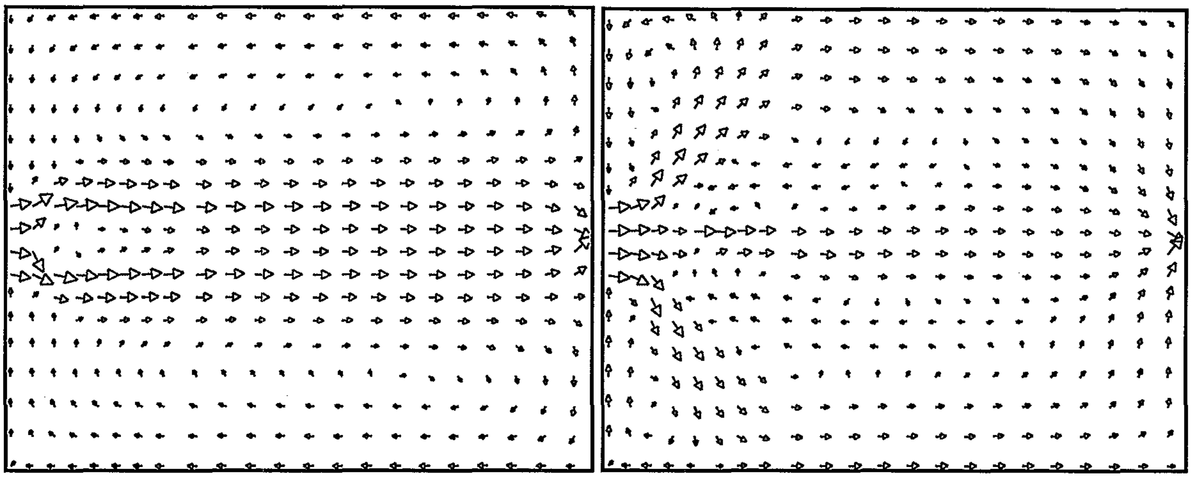
A properly designed displacement ventilation system is efficient in removing pollutants from the ventilated space. This means an efficient use of ventilation air. Several questions on how the systems should be designed to achieve optimal efficiency are still unanswered. Variations in room geometries and air supply/exhaust arrangements can change the flow conditions. Settling contaminants (particles) are difficult to control.

Mixing and flow recirculating in a room influence the local ages and the local elimination of polluted air. Good ventilation cannot be achieved by only changing (increasing) ventilation flow rates. It is shown here that the air quality and the whole air renewing process in the room is dependent on buoyant forces and particle characteristics.

Recirculating counteracts the fresh air exchange process. Contaminant removal is not optimal in a mixed flow system where part of the fresh (young) air is removed in the exhaust outlet. In an optimal system, internal (old) air is given a high priority for leaving the room, and external (incoming air) a low priority. Recirculating and mixing mean an increase in the local mean age of air in the affected regions of the room, and contaminant concentrations may reach dangerous levels.

Recirculating governed by air supply gradients and thermal gradients

To illustrate what has been said above, two examples are shown in Figure 1. By changing the air supply unit (diffuser) the efficiency of the ventilation air flow through the room is altered from an inefficient ventilation flow with an air change efficiency ε_a of 31 %, in Figure 1a, to an efficient flow with an air change efficiency of 67 % in Figure 1b. The figure shows examples of numerical age calculations [1].



a) $\varepsilon_a = 31$ %   b) $\varepsilon_a = 67$ %

Figure 1. Different flow patterns through a ventilated room showing the influence of air distribution and recirculating flow on the room air change efficiency, ε_a. An efficient flow is characterized by one-way flow orientation, high air change efficiency and short recirculating zones.

In a displacement ventilated room, where low-temperature air is supplied from the air terminals a vertical temperature gradient is initiating a re-directional flow movement shown in Figure 2. Similar flow phenomena are found in literature [2, 3].

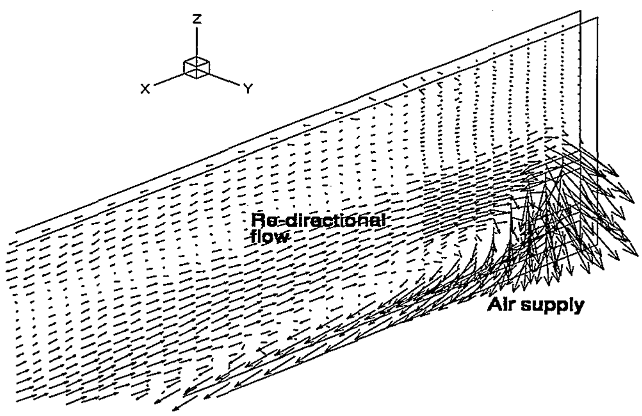


Figure 2. Vertical thermal gradient influenced recirculating in a displacement ventilated classroom.

Airborne particles

Owen et al [4] classify indoor air particles (aerosols) into the following groups: bioaerosols (plant and animal), mineral, combustion, home/personal care and radioactive aerosols. Particles here may be very small and remain airborne for long periods, or quite large and only remain in the air for short periods. Mineral fibres are used extensively in building materials. They are manufactured from glass, rocks, ceramics, etc. Most of the combustion aerosols are in the respirable range and need to be considered when designing an air quality control system. Tobacco smoke is a well-known complex problem substance in this group. Also, there is a concern that small particles from motor vehicles, especially diesel exhaust, can contribute to the development of different diseases, e.g. asthma. Chemicals, including sprays, used and generated in homes and offices present a health hazard by their chemical nature and their presence in the circulating indoor airstream. Radioactive particles, i.e. radon progeny, are unwelcome elements in the indoor environment. They are ultra small and may attach to larger particles. An efficient ventilation system can, in many cases, be useful in controlling exposure rates.

A size distribution of indoor air aerosols shows a wide variation in particle diameter from ultra fine particles to big particles with totally different aerodynamic behaviour in the air. In this investigation it is assumed that the removal of very small non-settling particles (behaving like gas contaminants) is acceptable with the ventilation system used. Therefore, bigger monodisperse particles with an aerodynamic diameter of 5 μm has been focussed on. A unit particle density of 1000 kg/m^3 is used. Particles of this size are respirable and they are typical indoor air particles that normally remain airborne during quite long periods of time. Because of their settling characteristics they are difficult to eliminate by conventional ventilation methods.

Two problems with settling particles in a ventilated room

The first problem is that settling particles have difficulties to leave the room via conventional exhaust outlets located above the breathing zone.

In a displacement ventilated room buoyant forces, i.e. convection flows around persons, are efficiently renewing the breathing zone air. The second problem arises when settling respirable particles, which are often generated below the breathing zone, entrain into the buoyant convective air streams around the humans and thus increase the particle concentration levels in the breathing zone [5, 6].

METHOD

Ventilation simulations in a classroom

In order to investigate the above mentioned problems with settling airborne particles and to show some general ventilation conditions in a displacement ventilated classroom, where 24 students and one teacher were present, a numerical study was carried out. The numerical method used for air and particle flow predictions is presented in previous work [5, 6]. A top view of the 2.5 m high room is shown in Figure 3. Twenty five rectangular blocks, each 0.34 m × 0.2 m × 1.4 m in size, represented the persons. The 1.4 m high blocks (persons) had a free surface area of 1.6 m^2, giving a constant heat flux of 60 W to the surrounding air. No other heat sources were present and this total heat load of 1500 W was appropriate to cover room mean air temperature and vertical temperature gradient requirements. Adiabatic wall conditions were assumed. The respirable 5 μm (indoor generated) particles came from two dotted line sources between the student lines in Figure 3. Particles were given an initial vertical velocity of 0.07 m/s at floor level. Set value for particle concentrations in the room was 100 μg/m^3. The incoming fresh air supply rate was 0.250 m^3/s. The supply air was equally distributed over two modelled air terminals (FMK-03; ABB Ventilation Products AB). An initial turbulence intensity of 10 % was given to the 19°C supply air. The exhaust outlet (0.40 × 0.30) m^2 was centred on the exhaust wall 2.1 m above floor level.

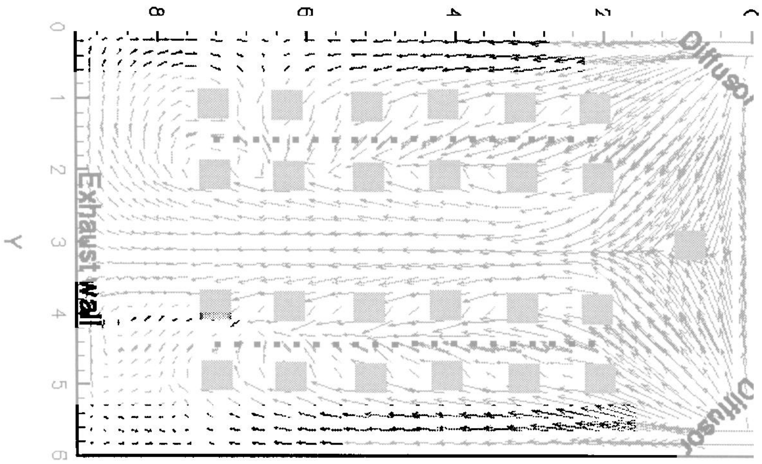


Figure 3. Top-view of the 2.5 m high classroom, where air and particle movements are investigated. The air flow structure is shown 0.1 m above floor level. Blocks represent persons (students) and the two dotted lines are particle sources.

RESULTS

The ventilation function with two different exhaust outlet configurations have been tested in the above described classroom. Relative comparisons of particle concentrations and local mean-age values of the ventilation air are reported.

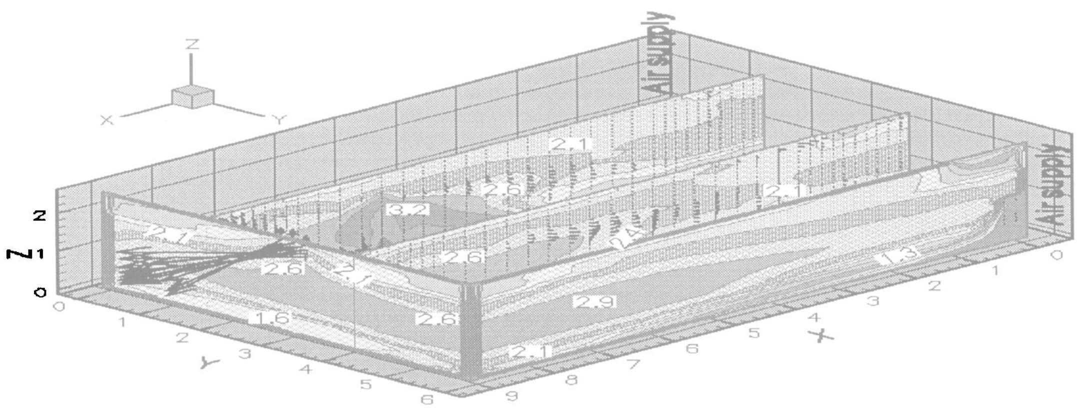


Figure 4. Particle concentrations in a displacement ventilated classroom. Settling 5 μm particles are difficult to eliminate via the exhaust outlet. Original exhaust outlet conditions given above are used. The dark areas stay for high particle concentrations.

This first numerical simulation shows that the aerodynamic characteristics of these particles make them difficult to eliminate by a conventional ventilation concept, where the exhaust outlet is located under the ceiling. The settling forces of the particles are in conflict with the upper zone location of the exhaust outlet. A new simulation was carried out. This time with three outlets at different locations. The original outlet was moved to the floor level and doubled in area by increasing the height. Two more outlets similar to the orginal one were added symmetrically at floor level, see Figure 5.

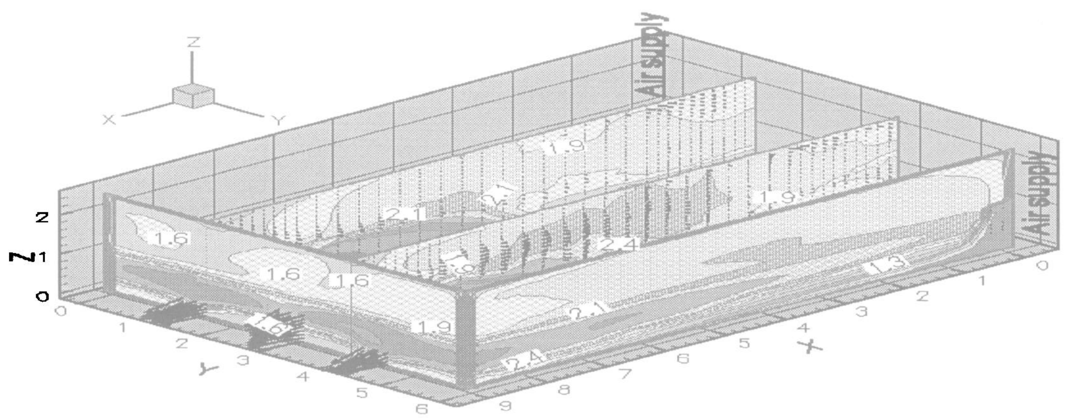


Figure 5. New exhaust outlet positions and simulated particle concentrations in the classroom. Compared to previous Figure 4, this figure shows lower particle concentrations in the breathing zone. The slowly settling particles are here more efficiently evacuated. Labeled relative concentration values in the two figures should be compared.

Naturally the new exhaust outlet conditions in Figure 5 lead to a less efficient air flow through the upper zones of the classroom. This is shown by local age of the air calculations in Figure 6.

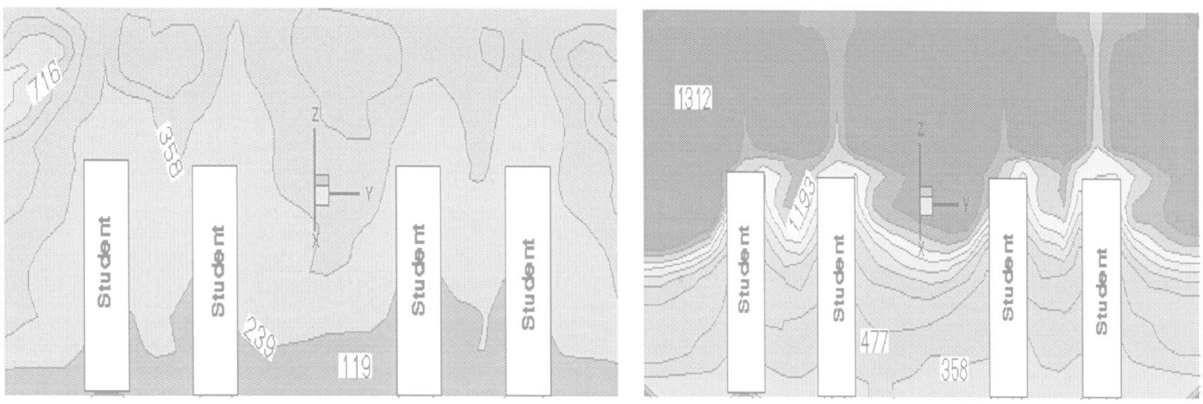


Figure 6. Local values of the mean age of the ventilation air. Results from simulations in Figure 4 (left) and Figure 5 (right). Fresh (young) air is continuously supplied into the breathing zone by buoyant convection forces. Labeled values are absolute values of the air age in seconds. High values mean low air change efficiency. White blocks represent students in the classroom.

More experiments with different locations of the outlets and different particle characteristics (particle sizes) are needed before the correct balance between particle concentrations in the room and general ventilation requirement are achieved.

DISCUSSION

With non-settling contaminants in a room, without specific local sources, displacement ventilation has a good chance to bring fresh air into the breathing zone and the contaminant concentration will stay below average room concentrations [7]. If, on the other hand, relatively strong local sources located below the breathing zone are influencing the particle concentration in the room, particle entrainment into the breathing zone is hard to avoid. Recent research shows that the air flow through a room should be well organized, well spread, and that the incoming velocity should be even with a low level of turbulence [8, 9]. Promising results with particle elimination in such flows are given in reference [10]. This paper shows the possibilities and difficulties in achieving optimal ventilation flow conditions with settling airborne particles. Thermal gradients as well as velocity gradients in the supply air cause un-wanted disturbances. Exhaust outlets located below the breathing zone are here shown to reduce respirable 5 μm particle exposures in the breathing zone. This leads, however, to a lower rate of ventilation in the room. Future research should aim at evaluating these results in order to find a more accurate ventilation design. CFD (Computational Fluid Dynamics) tools will be useful for this work. Validation work on particle generation models is also important.

ACKNOWLEDGMENTS

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