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SUMMARY

Air conditioning of premises is currently often carried out by employing displacement ventilation, in which the pattern of air movement is determined by convection streams from heat sources. Pollutants emitted by occupants are entrained by upward convection streams generated by the occupants and flow towards the ceiling. Whether the pollutants are extracted immediately with the exhaust air is dependent on the intensity of the convection streams and the rate of supply air flow at floor level. Unfortunately, pollutants are often transported down again to lower levels in the room, and there is then little difference between displacement and mixing ventilation. However, a beneficial effect of the convection stream around a person is that it entrains air from floor level. This article discusses the extent to which this improves the quality of the air in the inhalation zone, based on measurements of both gaseous and particulate concentrations in a conference room.

Introduction

During the 1980s, it has become increasingly common to ventilate premises by supplying air that is subcooled in relation to the room temperature, and admitting it into the premises with low velocity at floor level. This gives rise to a displacement air flow from the floor to the ceiling, assisted by thermal forces from heat sources in the premises. The principle is that the pollutants generated are transported by the convection streams from the heat sources towards the ceiling, where they are extracted with the exhaust air. However, this assumes a ventilation air flow rate which is at least equal to the sum of the convection flow rates from the heat sources in the premises.

If displacement ventilation is employed with normal air flow rates, the natural convection flows generate mixing flow in an upper zone, where the content of pollutants will be higher than in a lower, cleaner zone. From the air quality aspect, the air flow rates should be determined so that the cleaner zone includes the occupied zone, i.e. up to 1.8 m above floor level. However, to achieve this the rate of air change must be appreciably higher than usual.

A feature that favours displacement ventilation even when the characteristic layer between the two zones, the so called front, is at a lower level than the inhalation zone is that the convection stream around the body of a person entrains air from floor level. Since cleaner air then surrounds the person's body, the quality of the air in the inhalation zone without consideration to the pollutants emitted from the body itself should become better than the quality of the room air at the same level above floor.

The article presents measurements of pollutant contents in gaseous as well as particulate form in the inhalation zone of a person. The results are compared with corresponding measurements in a neutral place in the room, in order to determine how the front level affects the quality of the air in the inhalation zone.

Air flow requirements

Even though the primary task of a ventilation system is to create good air quality in a building, economic considerations often make it advisable to expand the task to control the temperature in the building. The demand for cooling is growing due to the increasing internal heat loads in premises, and also due to the better air-tightness and insulation of modern buildings. It is thus becoming of increasing importance to supply premises with large quantities of subcooled air, but without the occupants perceiving the air movements or temperature gradients as uncomfortable. Analogously with the upper cooling limit in mixing ventilation which, if exceeded, will give rise to unacceptably high air velocities in the occupied zone, there is also an upper limit of cooling capacity in displacement ventilation which, if exceeded, may cause both high air velocities and low air temperatures at floor level.

When good ceiling diffusers are employed in mixing ventilation systems supply air temperatures down to 14°C, giving 10°C difference in temperature, can be used without causing uncomfortable draughts. Displacement ventilation with supply air at floor level is, contrarily, very sensitive to low supply air temperatures; partly because the cold down-draught from the diffuser generates high velocities near the floor in the so called near zone and partly because of cold airstreams over the floor. Our experience shows that the supply air temperature from low-velocity supply air devices should not be less than 19°C in comfort environments if people engaged in seated light work are not to experience discomfort. The vertical temperature difference between 1.1 m and 0.1 m (sitting head and ankle heights) will be about 2°C at a room temperature of 24°C. This can be compared with the ISO 7730 standard, which allows 3°C per meter without considering displacement ventilation and may be acceptable at higher temperatures or in rooms with higher degree of activity.

This restriction on the supply air temperature to conventional low-velocity supply air devices results in a significantly higher air flow for a specific heat load. Clearly, this implies a considerable increase in the size and cost of the installation, assuming cool air is available through free cooling or mechanical cooling.

Against this background, Fläkt has launched an entirely new type of low-velocity supply air diffuser, the top part of which is equipped with an induction chamber. The design enables room air to be drawn into the chamber and mixed with the cold supply air. Due to the induction chamber a primary air temperature of about 16°C can be chosen while retaining the supply air temperature of 19°C with no change in room temperature. In other words, a room can be cooled with this type of low-velocity device using a considerably lower air flow compared with those of conventional design.

Since the room air is stratified as a result of the vertical temperature gradient, the induction air principally consists of room air at the same height above floor as the induction chamber of the diffuser. At lower levels, the induction principle thus gives rise to a certain amount of mixing of the room air, whereas the flow conditions above the induction chamber level remain practically unaffected. As a result, provided that the top of the diffuser is located on a level equal as or lower than the inhalation zone, induction causes no significant impairment of the quality of the inhalation air.

An analysis of the air flow requirements in a building can thus provide more detailed knowledge of when it would be advantageous to employ low-velocity supply air diffusers with induction chamber, and will also reveal the applications in which displacement ventilation will be most beneficial. The demand for a certain supply air flow to the premises may be related to the requirement that an acceptable air quality should be maintained in the premises or to the requirement that a certain maximum room temperature should not be exceeded during cooling operation.

A conference room, in which the heat from the occupants can be assumed to be the dominating source of heat, is in this context an interesting case to study in more detail. Assuming an occupant heat of 100 W per person, the minimum air flow requirement is 8.3 l/s per person in order to maintain a constant room temperature with air that is subcooled by 10°C below the room temperature, if mixing ventilation i employed. This rate of air flow is considered to be acceptable from the air quality aspect and provides, for instance, an increase of about 600 ppm in the CO_2 content under steady-state conditions which together with a background level of 350 ppm gives 950 ppm in the room (1). If air at 10°C below the room temperature is supplied, the air flow rate required will be roughly the same, regardless of whether it is considered from the aspect of removal of heat or removal of pollutants from a person.

To maintain room temperature at 1.1 m height with displacement ventilation it is not necessary to supply cooling for the entire heat output load since a part of it affects the upper part of the room resulting in a higher air temperature near the ceiling and thus a higher extract air temperature (2,3). This also results in a correspondingly lower air flow requirement for maintaining the room temperature at the 1.1 m level. Assuming a reduction of 15% in the example above, an air flow rate of about 14 l/s per person would be required when conventional low-velocity supply air diffusers are used and the supply air is subcooled by about 5°C below the room temperature. Since the Fläkt low-velocity diffuser with induction chamber can handle about 50% higher differences between the supply air and room temperatures, while leaving the temperature gradient unaffected, they would have to supply an air flow of only about 9 l/s per person in order to maintain the room temperature. The induction principle thus allows a room to be cooled by the displacement technique at practically the same air flow rate as in mixing ventilation. Since pollutants from persons are generated concurrently with heat, the concentration of pollutants in the upper zone will be roughly the same as that provided by mixing flow. At air flow rates less than 10 l/s per person, the front between the two zones under steady-state conditions is below the head height of a seated person. As outlined below, the air quality in the inhalation zone under certain conditions may still be better, since the inhalation air is taken from a lower level in the room, due to the convection stream around the occupant's body.

In office premises, the internal heat load consists of heat from the occupants but also from the lighting and computers. In addition, an external solar heat load is also applied during a large proportion of the season. The required air flow for maintaining an upper limit of room temperature during the summer will thus be higher than when the internal heat load consists exclusively of heat from the occupants. The cooling requirement will therefore be the design parameter for air flow in office premises with airborne cooling, and the air quality at this increased supply air flow rate will therefore be adequate, regardless of the ventilation method. But if no demands are made on the upper limit of room temperature and thus no cooling facilities are installed, the minimum air flow is selected to provide the required air quality. The consequence of this will be that the front in displacement ventilation will reach such a low level in the room that the air quality improvement will be marginal as compared to mixing ventilation.

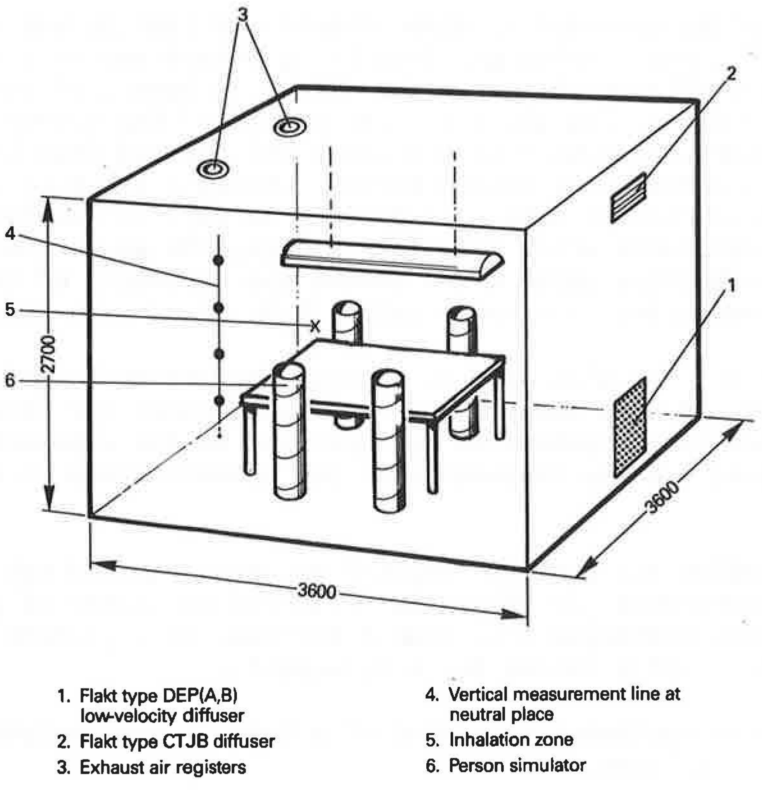

Fig. 1. Test room which simulates a small conference room with a floor area of 13.0 m^2.

Test conditions

Measurements were carried out in a test room with a floor area of 13,0 m^2 and a ceiling height of 2,7 m (see Figure 1). The room simulates a small conference room which is assumed to be in an inner zone, and thus has no external heating or cooling loads. The internal heat loads amount to a total of 36 W/m^2 of floor area and consist of 4 persons at 100 W each and overhead lighting of about 75 W. The accessible floor area 2.25 m^2 per person is also representative for bigger conference rooms. In displacement ventilation, the Fläkt type DEPA and DEPB wall-mounted, low-velocity diffusers, with and without induction chamber respectively, were used, whereas the Fläkt type CTJB wall-mounted diffuser was used for mixing ventilation. Type KGE exhaust air registers were located in the ceiling, and the supply and exhaust air flows were in balance.

In the normal case, the air flow rate is 40 l/s, i.e. 3.0 l/s per m^2 of floor area, and is determined to meet the cooling requirements. Some tests were also carried out at 20 l/s, i.e. corresponding to the minimum air flow of 5 l/s per person which is permissible in Sweden, and the room temperature then rose during the test, since the cooling requirements were not met.

The air quality provided by displacement ventilation was assessed by the vertical gas concentration gradient being determined at a neutral place in the room (Figure 1), where the direct influence of heat sources and supply air diffuser was the slightest possible. The tracer gas simulates pollutants generated by occupants and emitted into the convection streams from four seated persons around a table in the test room. These seated persons were real persons as well as simulated by means of sheet steel cylinders which were 1.25 m high, 250 mm in diameter and were heated by a heating cable wound around the periphery of the cylinder. The tracer gas consisted of nitrous oxide (N_2O) mixed with air.

The tracer gas was also used to analyse the extent to which the convection streams around the person entrained cleaner air from a lower level. The pollutant concentration was measured in the inhalation zone of one of the persons and was compared with the concentration in the neutral place.

A corresponding air quality analysis was also carried out in the form of particle measurements, in which the pollutant consisted of gasified paraffin oil, with particles less than 2 microns. Real persons have been using clean room clothes during the measurements.

The measuring equipment consisted of a Uras 7N gas analyser and a Met One 200 particle analyser.

Results

The air flow rate of 40 l/s selected to suit the cooling requirements of the test room, i.e. 10 l/s per person, is considered to be fully adequate for providing acceptable air quality even in the case of mixing ventilation, provided that most of the pollutants are generated by the four persons in the room. The CO_2 content, for instance, with four persons present in the room is estimated to be about 850 ppm after steady-state conditions have been established and at a background level of 350 ppm.

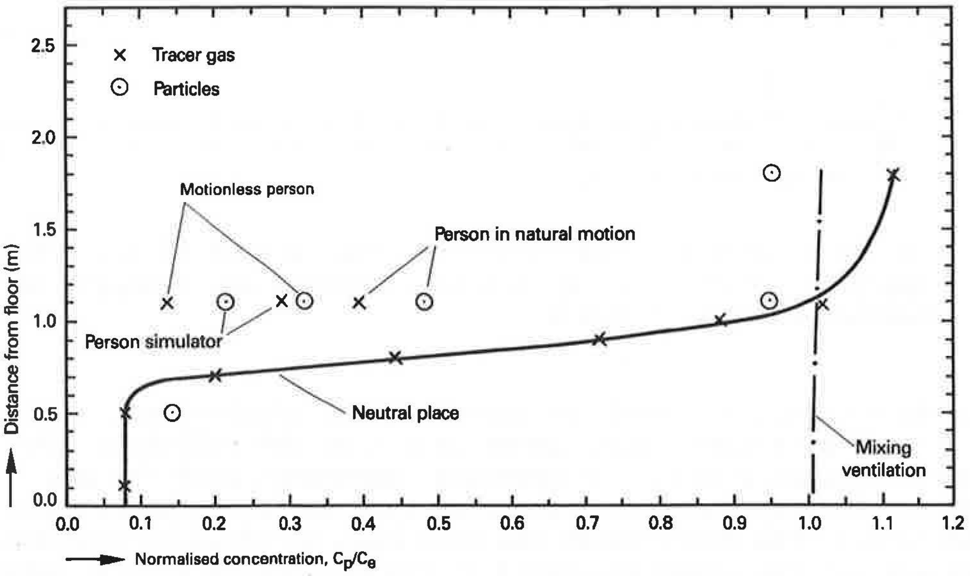

Fig. 2. Pollutant concentration at an air flow rate of 40 l/s with a supply air diffuser without induction and a supply air undertemperature of 6.6°C (C_p is the concentration at point p and C_e is the concentration in the exhaust air).

Figure 2 shows that this air flow rate in displacement ventilation using a diffuser without induction results in the front being low at, about 0.7 m above the floor, with very clean air in the lower zone. The figure shows the measured gas concentration at different heights above the floor at the neutral place in the room, with tracer gas generated in the convection stream from one of the person simulators. The height above the floor where the gas concentration starts to increase substantially thus indicates the front. Figure 3 illustrates corresponding tracer gas measurements with the induction chamber diffuser. In this case, induction provides a more distinct front, 0.9 m above the floor, with a steeper concentration curve due to some mixing in the lower zone. The concentration in the upper zone above head height will on the other hand be practically unchanged.

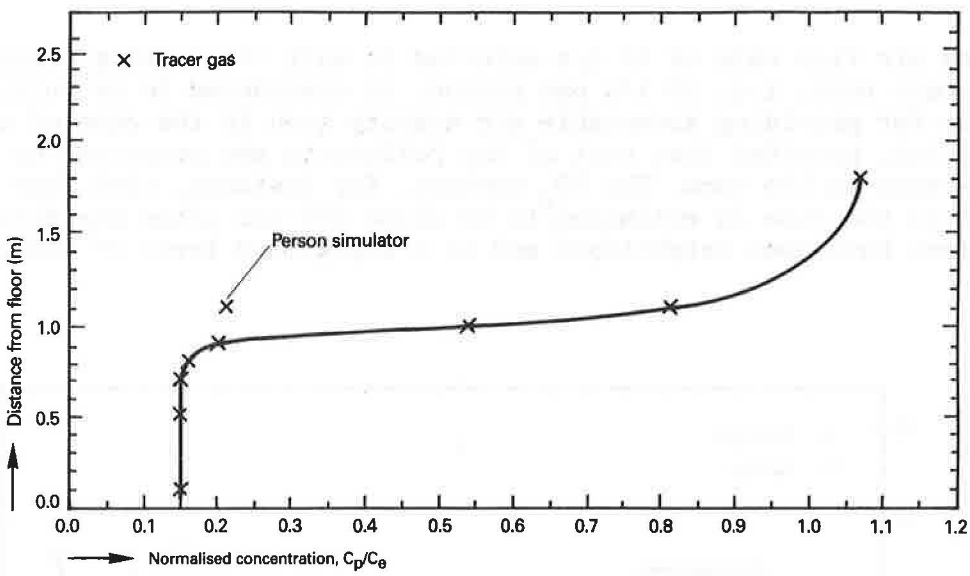

Fig. 3. Pollutant concentration at an air flow rate of 40 l/s with a supply air diffuser with induction chamber and a supply air undertemperature of 6.4°C.

In these cases, the vertical concentration gradient was also measured in the form of particles, using paraffin oil as the pollutant. The results are shown in Figure 2 and 3. As expected, agreement with the gas measurements is very good. By increasing substantially the concentration of paraffin oil, the front level has also been verified by studying visually how far the smoke generated in the convection streams penetrate down into the room.

The concentrations in an imaginary inhalation zone at one of the person simulators are shown in both of these figures. Whether the pollutant is generated in one or more of the convection streams of the other simulators affects the results only marginally. These figures demonstrate clearly that the inhaled air is cleaner than the room air at a given height above the floor and that it rises from a lower level due to the upward convection stream occurring around a person's body.

With an air flow rate of 40 l/s and one seated person with the inhalation zone about 1.1 m above the floor, the inhaled air will be up to 5 times cleaner than in mixing ventilation. As is clear from the figures, the pollutant concentration in mixing ventilation is even in the room and the room air as well as inhaled air assume nearly the same concentration as the exhaust air. The marked improvement in the cleanliness of the inhaled air in displacement ventilation has been recorded using a person simulator as well as an actual person who sat completely still. If a person makes natural movements as he would at a conference table, the improvement will be somewhat less pronounced, and the inhalation air will be 2 to 3 times cleaner.

It should be noted here that, if the room is to be cooled at an air flow of 40 l/s, the required supply air temperature will be so low that a conventional low-velocity diffuser without induction will cause air temperatures at the floor which will give rise to discomfort. The solution lies in either an increased air flow rate with higher supply air temperature, which will result in an increase in both space and investment requirements in the plant, or a diffuser with an induction chamber employed at an unaltered air flow. The latter alternative thus results in appreciably lower installation costs.

Considering a conference room in which the room temperature is allowed to rise without any upper limit being set and in which the air flow is thus selected to meet the air quality requirements, it may be interesting to carry out corresponding measurements at the lowest conceivable flow of 5 l/s per person, i.e. at a supply air flow of 20 l/s. In this case, it would be natural to select a conventional diffuser without induction, since no demands are made on the room temperature. As illustrated by Figure 4, the front will now be at a very low level in the room, 0.4 m above the floor, with essentially higher concentration in the lower zone as a concequence of a less stable air flow along the floor. As shown in the figure, in view of the natural movements of a person, the inhaled air in this case will be insignificantly cleaner than in mixing ventilation.

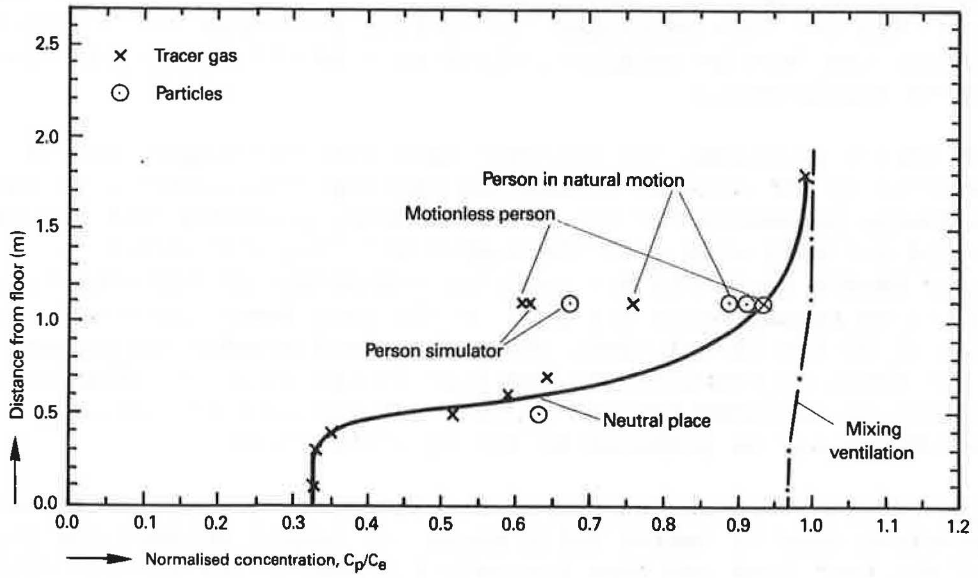

Fig. 4. Pollutant concentration at an air flow rate of 20 l/s with a supply air diffuser without induction chamber and a supply air undertemperature of 7.3°C.

Conclusions

In conference rooms with normal ceiling height, in which the pollutants are principally generated by the occupants and are thus entrained by the upward convection streams around the people, displacement ventilation may provide better air quality in the inhalation zone around seated people than mixing ventilation, provided that the air flow rate is sufficiently high. At an air flow of 10 l/s per person, for instance, the inhaled air of seated persons who are sitting perfectly still in a conference room will be substantially cleaner, in spite of that the front is slightly below the head height of the seated persons, due to the fact that the convection streams around the persons entrain cleaner air from the lower zone. However, the improvement in the quality of the air in the inhalation zone is reduced by natural movements of the people. At the minimum flow rate of 5 l/s per person permissible in Sweden, displacement ventilation provides no appreciable improvement in the quality of the inhaled air as compared to mixing ventilation, since the front is far below the inhalation zone.

In the case of other pollutants which are not generated in the upward convection streams, the pattern may be entirely different. Reference (3) shows, for instance, that pollutants which basically have the same density as the air and are generated in neutral places in the room may locally have very high concentrations and may be entrained into the convection stream of a person, thus giving rise to elevated concentrations in the inhaled air.

Public premises often have high cooling requirements why air supply diffusers with induction chamber should be used in displacement ventilation, so that the lowest possible supply air temperature can be employed. The air flow necessary for cooling the premises in mixing ventilation can thus be retained, which will result in similar space and investment requirements.

In office premises, the internal heat load originates not only from heat emitted by the occupants, and the cooling requirement will therefore be the design parameter for the air flow rate, provided that the premises are cooled entirely with air. The higher air flow rate often up to 50 l/s will then ensure excellent air quality, regardless of the ventilation method. If no requirements are made on the room temperature and a minimum air flow of 10 l/s is selected, the high upward convection streams will cause the front to penetrate so far down in the room when displacement ventilation is employed that no improvement can be expected in the quality of the inhaled air as compared to mixing ventilation.

In summary it can be said that displacement ventilation is most appropriately used in public halls where the people account for the larger part of the heat load and that low-velocity supply air devices with induction chamber should be selected whenever mechanical cooling is included in the installation.

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