Air quality in the near zone of humans with different ventilation strategies

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ABSTRACT

The concentration in the convection flows of resuspended particles from the floor area was experimentally investigated under laboratory conditions with different ventilation strategies. It was concluded that the number of small particles transported into the breathing zone was large with a forced resuspension; however there seemed to be little risk of resuspension of particles from the floor due to the air supply under normal conditions. The geometry of the simulators and the layout of the room had a big influence on the exposure. The particle concentration in the convection flows was much higher with displacement than with mixing ventilation indicating a higher exposure risk. In previous studies of particle exposure the concentrations are mostly presented in particle mass but here the results are presented in number concentration. As potential health problems are more closely associated with particle number or surface area than with particle mass this study can be of interest when designing a ventilation system.

1. INTRODUCTION

The contaminant distribution and air change in a ventilated space and especially in the near zone of a human being is essential for the air quality in the inhaled air. In order to use the ventilation air effectively it must be distributed to the parts of the room where people are present. This is important both from energy and health aspects. The increased frequency of allergy in the population has emphasised this even more.

In mixing ventilation the air is supplied with relatively high velocity and the air flow pattern within in the room is mostly depending on the ventilation layout. In displacement ventilation the air is supplied with a small under-temperature, compared to the room air, and with a low velocity at a low level in the occupied zone. The air flow pattern in the room is then mainly governed by the convection flows created in the room from people, computers and other heat sources. These convection flows are of course also present in mixing ventilation but may be disturbed by the supply air flow.

The air quality in different parts of the room is depending on the contamination sources and their distribution in the room and of course the ventilation system. Of special interest is the air quality in the near zone of humans i.e. the inhaled air quality.

The transportation of contaminants into the convection flows created by warm sources like humans is influencing the air quality in the inhaled air. The objective of this paper is to present experimental results of the transportation of contaminants into convection flows under different conditions, different ventilation systems and different positions of the humans.

In Mundt (1996) a lot of measurements of local air quality indices in plumes above different heat sources and in positions outside the plumes are presented with tracer gas as pollutant. The difference in values in the convection plume compared to elsewhere in the room is pointed out; i.e. the influence of the local flow around a convection source is essential. The results are mostly from steady state measurements but the influence of a door opening on the values is also demonstrated.

In Mundt (2001) the decay of resuspended particles in a displacement ventilated room after a disturbance has been presented, measurements were however only made of particles greater than 0,5 μm. As smaller particles are able to reach deeper into the lungs and have a larger surface area although their mass is negligible a study of their behavior is of interest.

There are some studies of resuspension of particles due to activity e.g. Thatcher and Layton (1995) who presented resuspension rates of particles in a residence due to different activities. The particle size range measured was 0,3 – 25 μm and concentrations presented as $\mu g/m^3$. They stated that the mass particle concentration for submicron particles was not affected by either cleaning or walking and that the particles 5 – 25 μm were most readily resuspended. The measurements were made in one room at the height 2 m above the floor and not in the vicinity of a person. Ferro et al (2004) have presented personal exposure measurements of particulate matter from human activities in a residence with no mechanical ventilation. The "personal cloud" effect expressed as mass particle concentration was found to be small in the range 0,3 – 1 μm. Unfortunately no numbers are given for particle number concentration. According to Donaldson et al (2001) potential health problems are more closely associated with particle number or surface area than with particle mass. Gomes at al (2005) have studied resuspension due to vibrations and air-puffs, and presented that although the disturbance lasted for ten minutes the particle resuspension only occurred for the first two minutes. Qian et al (2006) recently presented results of a study concerning the dispersion of exhaled droplet from patient to patient or health care workers in a hospital with different ventilation systems and concluded that displacement ventilation should be avoided in hospital wards.

2. MEASUREMENTS

In order to see how resuspension influenced the particle concentration in convection flows measurements were made in a test room. The test room 3,6 x 4,6 x 2,7 m (*W* x *L* x *H*) is situated in a laboratory with rather stable temperature conditions. The walls and ceiling are painted and the floor covered with a linoleum carpet. The room was mechanically ventilated with 175 m^3/h equal to an air change of 4 ach, either by displacement or mixing ventilation. The supply air was cooled and filtered in a Hepa filter. The supply temperature was set so that all heat emitted within the room was evacuated by the ventilation air flow. The layout of the room can be seen in Figure 1.

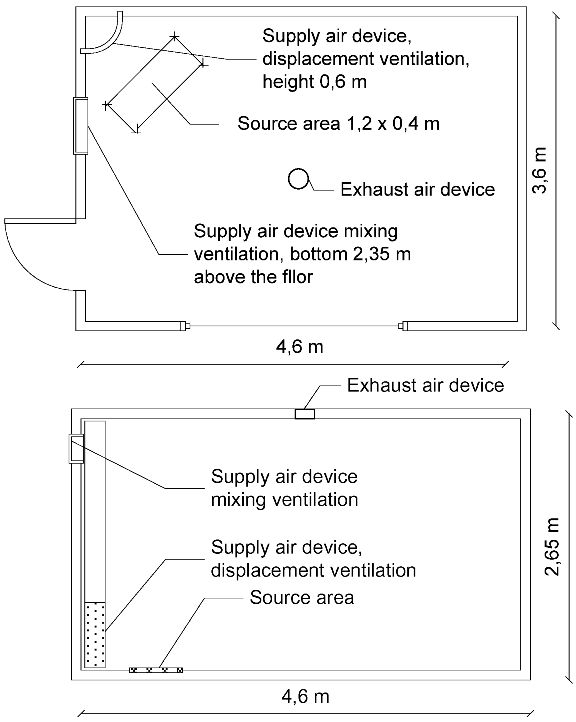
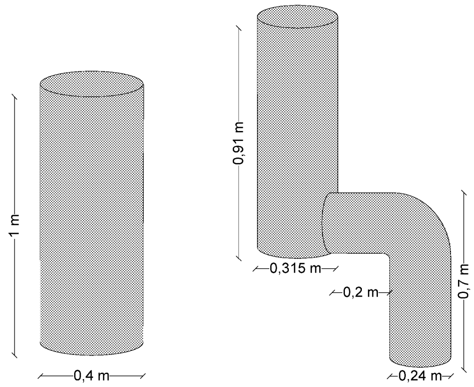


Figure 1. Plan and elevation of the test room.

In the room two person simulators, consisting of painted ventilation ducts, were positioned each with a power of 100 W inside (electric bulbs), in some of the tests one of the simulators was replaced by a real person. The simulators were of two types, see Figure 2, where model A represents a simplified sitting person (SSP) used in many previous studies, model B represents a sitting person (SP) adopted from Mattsson (1999).



Model A (SSP)   Model B (SP)

Figure 2. Two different kinds of person simulators.

The simulators were positioned in different ways in the test room, either as two SSPs or one SSP and one SP sitting at a desk, see Figure 3-4. More configurations can be found in Mundt & Petersson Blomberg (2007).

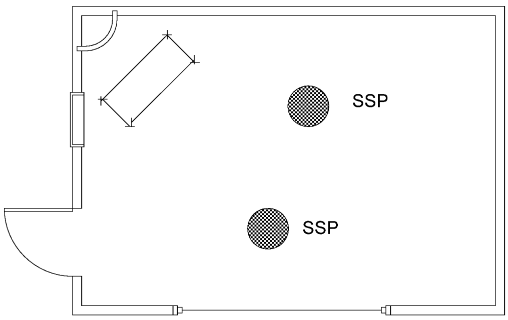


Figure 3. Test room with two SSPs

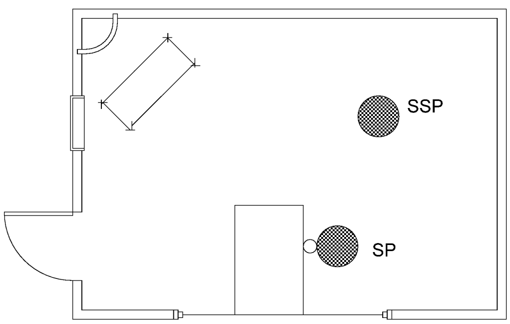


Figure 4.Test room with one SP at the desk and one SSP

The particle concentration was measured in the convection flows close to the simulators at height 1 m at the SSP and at height 1,15 m at the SP. Some measurements were also made in the room outside the convection flows at height 1,15 m and in the exhaust.

A limited amount of the particulate matter, Standard test dust R10 (chemical analysis >95% SiO_2, specific gravity 2,65 g/cm^3) from Particle technology, particle size distribution see Table 1, was spread in front of the displacement air supply device before each test.

Table 1. Test dust particle size distribution.

Particle size diameter (μm)	Cumulative percentage by weight below stated size
10	98,2
7,6	74,4
5,1	48,6
3,9	22,9
2,9	10,7
2,3	1,15

The particle concentration was measured with three particle counters, two condensation nuclei counters, PSI P-trak Model 8525 with a measurement interval 0,02 to 1,0 μm (concentration range 0 – 5 $\cdot 10^5$ particles/cm^3 and sample flow rate 100 cm^3/min) and one Grimm Aerosol Spectrometer Model 1.109 with a measurement range 0,25 to 32 μm, which can be divided in 31 different intervals (concentration range 1 – $2 \cdot 10^3$ particles/cm^3 and sample flow rate 1200 cm^3/min). The particle counters were placed outside the test room and the air sampled through Tygon tubes.

Measurements were made as follows:

- Test dust was spread out in the source area
- Stable temperature conditions were obtained with the chosen layout
- Particle concentration recording was started
- One person entered the room and walked back and forth in the source area for 5 minutes
- The person left the room
- Particle concentration was recorded during the whole period and the decay.
- The room was cleaned from test dust

As can be seen in the following figures the maximum number of particles obtained in the different experiments was not the same, this is because the amount of dust was not exactly the same at each test. There was however a significant difference in maximum number concentration between the results with displacement ventilation compared to mixing ventilation in all tests.

The figures presented do not have the same scale on the Y-axis in order to make the figures more clear.

There were no traceable concentrations in the room at stable conditions, implying that the Hepa filter removed practically all particles from the supply air and that the supply air flow did not cause a resuspension of the test dust from the source area.

Before the measurements were started tests were made with no test dust in the source area in order to see if a person himself produces particles which have to be taken into account. The result of this test was that the influence of a person compared to the concentrations obtained in the measurements with test dust was negligible (less than 1%).

3. RESULTS

Figure 5 and 6 present measurements with layout according to Figure 3 and with displacement and mixing ventilation.

In the figures concentrations measured with the two P-traks are shown and also the concentration of particles in the range 0,25 to 1,0 μm measured with the Grimm. The difference between the curves are the particles in the range 0,02 to 0,25 μm i.e. the ultrafine particles hazardous to the health. As can be seen from Figure 5 the amount of ultrafine particles transported in the convection flow during the forced resuspension is quite large.

Figure 5 and 6 also show that the particle concentration was much higher with displacement ventilation than with mixing ventilation. Although the decay rate after a disturbance is much faster with displacement ventilation (3 to 4 times the decay rate obtained with mixing ventilation) than with mixing ventilation the total exposure due to the disturbance might be larger.

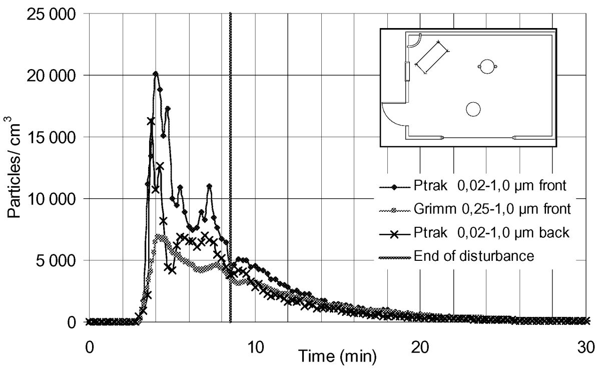


Figure 5 Displacement ventilation. Particle concentration before, during and after a person entered the room, walked around for 5 minutes and then left the room. The particles were measured on the two sides of the SSP with three particle counters.

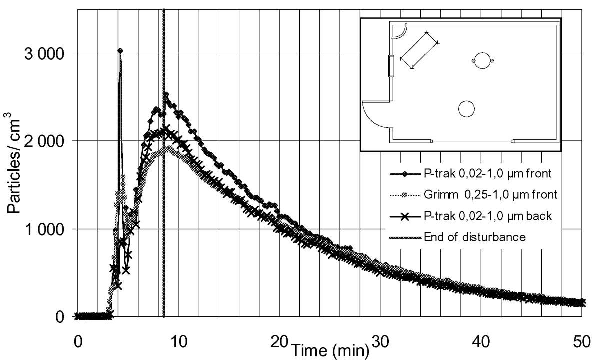


Figure 6. Mixing ventilation. Particle concentration before, during and after a person entered the room, walked around for 5 minutes and then left the room. The particles were measured on the two sides of the SSP with three particle counters.

The curves of particle concentration also look quite different with displacement ventilation compared to mixing ventilation. In the first case the concentration increases quickly showing a fast transportation of the particles into the convection flow and then starts to decay before the disturbance ends indicating that the amount of particles resuspended during the disturbance decreases. In mixing ventilation the concentration increases slowly during the disturbance period and starts to decrease only after the end of the disturbance. This different pattern in displacement and mixing ventilation was observed in most cases.

In Figure 7 is shown how the table and the geometry of the simulator influence the air flow around the sitting person compared to the SSP (measurements with layout according to Figure 4). At the SSP the convection flow looks different compared to at the SP where the flows from the "leg" part and the "body" part are more separated.

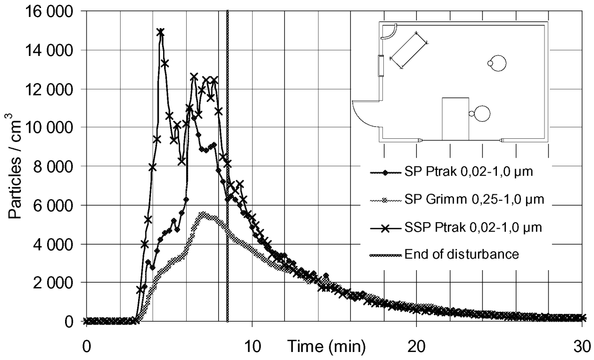


Figure 7. Displacement ventilation. Particle concentration before, during and after a person entered the room, walked around for 5 minutes and then left the room. The particles were measured on the SP and the SSP with three particle counters.

In order to see how representative the measurements with simulators are, some measurements were also made with a real person instead of one of the simulators, Figure 8. As can be seen from Figure 7 and 8 the results were almost the same with a real person sitting at the table as with a simulator.

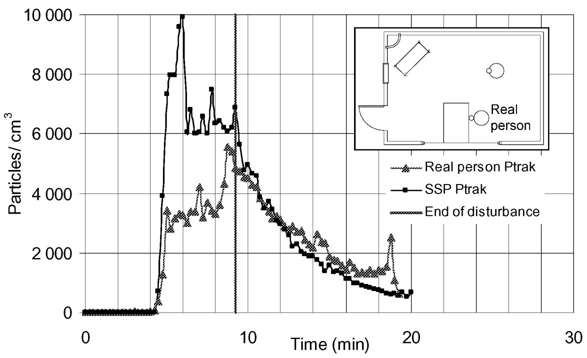


Figure 8. Displacement ventilation. Particle concentration before, during and after a person entered the room, walked around for 5 minutes and then left the room. The particles were measured on the real person and the SSP with two particle counters.

In figure 9 another example of the similarity in the results with a real person and a simulator is shown.

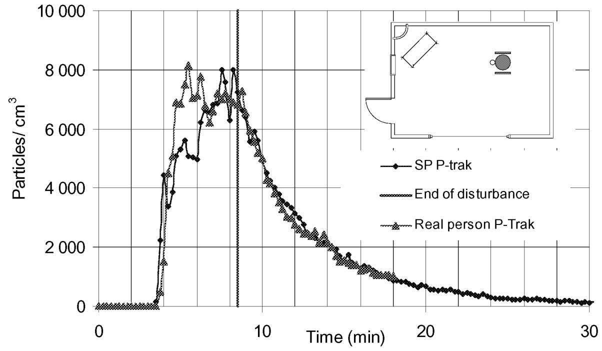


Figure 9. Displacement ventilation. Particle concentration before, during and after a person entered the room, walked around for 5 minutes and then left the room. The particles were measured on the real person and a SP with particle counters. (Not in the same experiment)

The large difference between the concentrations in the convection flow compared to in the room and in the exhaust can be seen in Figure 10 indicating a direct transport of the contaminants to the convection flows also for the SP.

The decay rate, calculated from the final slope of the decay curve, close to the person is 9 1/h compared to a decay rate of about 5 in the exhaust and in the room air.

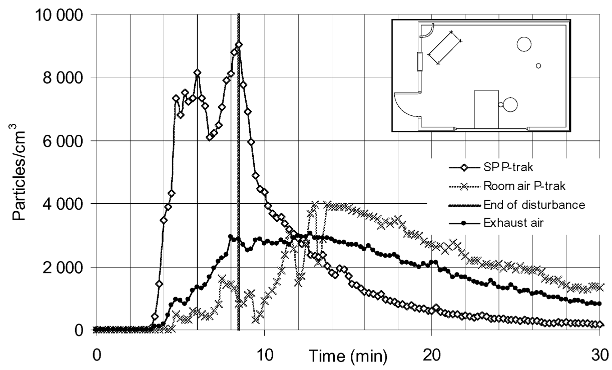


Figure 10. Displacement ventilation. Particle concentration before, during and after a person entered the room, walked around for 5 minutes and then left the room. The particles were measured on the SP, in the room and in the exhaust.

The decay rates close to the simulators for different configurations varied from 9 to 19 1/h with displacement ventilation. With mixing ventilation the decay rates close to the simulators, in the room and in the exhaust was always equal to 4 implying a fully mixed situation

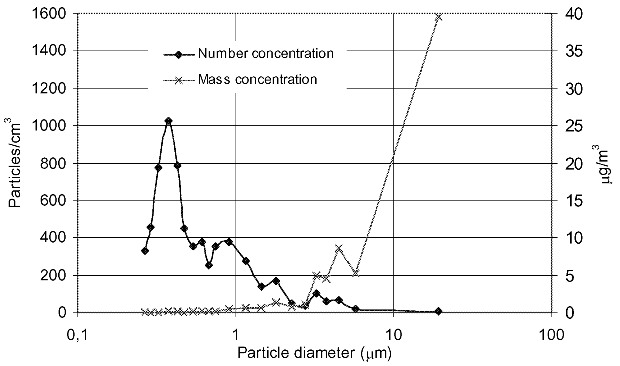


Figure 11. Maximum mass and number concentrations measured as in Figure 7 with the Grimm instrument.

In Figure 11 the maximum values in 21 different particle size intervals measured with the Grimm instrument at the measurements presented in Figure 7 is shown, the number concentrations in the different intervals are presented as well as the mass concentration calculated from the mean diameter in each interval and the data for the test dust. As can be seen the mass concentration for the smaller particles is negligible but not the number concentration. The concentrations measured are of course also dependent on the test dust used.

4. CONCLUSION

The large influence of the convection flows on the transportation of contaminants could be clearly seen in the measurements presented here. This was also shown in previous studies Mundt (1996 and 2001) where contaminants, represented by both tracer gas and particles, were being generated in different parts of the room. The contaminant removal effectiveness and the local air quality indices were much depending on the position of the contaminant source, both the level and the distance to the heat sources present in the room.

There seem to be little risk of resuspension of particles from the floor due to the air supply under normal conditions, however with a forced resuspension due to walking in a contaminated area high concentrations of resuspended particles were measured especially in the fine and ultrafine range. The particle concentration in the convection flows was much higher with displacement than with mixing ventilation indicating a higher exposure risk. The geometry of the simulators and the layout in the room had a big influence on the exposure.

The concentration of particles in the breathing zone due to resuspension with different ventilation systems ought to be further investigated.

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