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DISPLACEMENT VENTILATION IN A CLASSROOM – INFLUENCE OF CONTAMINANT POSITION AND PHYSICAL ACTIVITY

Magnus Mattsson
Royal Institute of Technology
Department of Built Environment
Box 88
S-801 02 GÄVLE
SWEDEN

Displacement ventilation in a classroom – influence of contaminant position and physical activity

Magnus Mattsson
Royal Institute of Technology, Dept. of Built Environment
Box 88, S-801 02 GÄVLE, SWEDEN

Synopsis

This study describes how the air quality in a displacement ventilated classroom can be influenced by the position of a contaminating person, and by the activity of a person who walks around in the room. Tracer gas measurements have been performed in a full scale mock-up of a classroom, with person simulators at the student's desks.

The spreading of contaminants from a person seems to be strongly dependent on the position of the person. The closer the contaminating person sits to the outlet terminal(s), the less of his/hers contaminants are spread in the room. Paradoxically, people sitting furthest away from the air supply were found to be provided with the least contaminated air. Physical activity, produced by a walking person, tends to increase the concentration of contaminants emitted from people in the room, whereas the air exchange efficiency actually can benefit from it. At all levels of activity tested in this study the displacement ventilation system provided significantly better air quality than a mixing system would.

Introduction

The question of how to ventilate classrooms has gained increased attention in recent years in developed countries, where the problem of allergies has become acute. The classroom contribution to the allergy problem might to some extent lie in harmful emissions from building and furnishing materials, but probably even more in the spreading of allergens from one student to the other; all possibly in combination with poor ventilation flow rates.

When new ventilation systems are to be installed in schools, the choice nowadays often falls on the displacement system – at least this is the case in northern Europe. Its reputation of providing good ventilation effectiveness is probably the main reason for this. Often a two-zone model is used to describe the functioning of the displacement system: The air supply at a low level creates a lower zone of fresh air, whereas the contaminants are to be found in an upper zone, which is well mixed by thermal plumes from heat sources in the room.

However, an interesting question is whether the supply air reaches all people in a densely populated room like a classroom. One may suspect that the supply air, as it flows along the floor, is "stolen" by the convection flow along the bodies of the people sitting closest to the inlet terminal(s), leaving no fresh air left for the people sitting far way from the supply. Furthermore, the often good ventilation effectiveness has been shown in some previous studies (see [1]&[2]) to be sensitive to physical disturbances, like people's movements.
This study aims to describe how the air quality in a large, densely populated and displacement ventilated room is influenced by the position of a contaminating person, and also by the activity

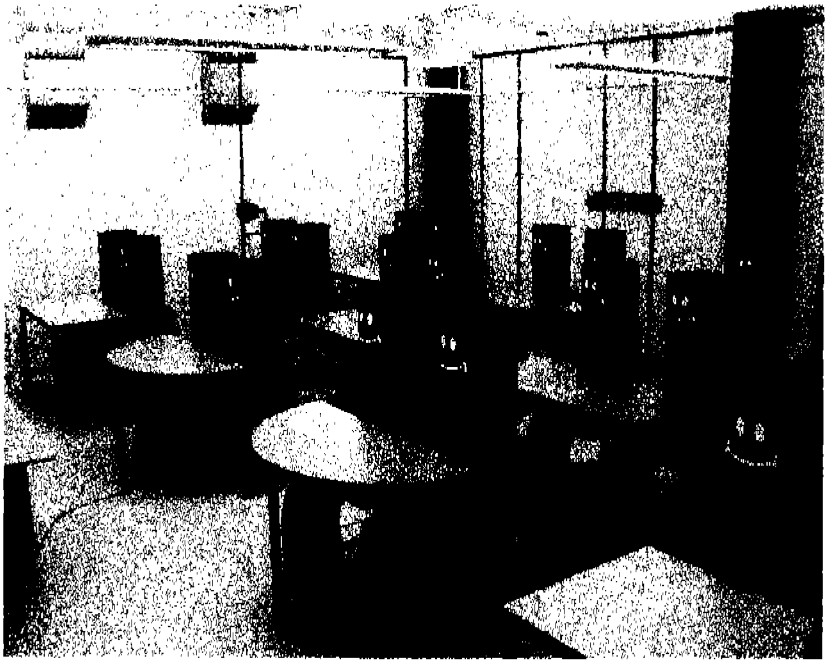

Figure 1. The classroom with the person simulators.

of a person who walks around in the room. To investigate this, tracer gas measurements have been performed in a classroom where students were represented by person simulators.

Method

The measurements were performed in a full scale mock-up of a classroom; size: 7.20x8.40 m, 3.00 m high. The well insulated classroom was situated in a laboratory hall, having an air temperature of about 22 °C. In the classroom, 24 students and a teacher were represented by person simulators (PS). Each PS was composed of one straight circular cylinder, constituting the main part of the body, and another, bent cylinder imitating the legs. The total area of a PS was 1.7 m^2, which is about the average of grown up (Caucasian) men and women. Each PS had an internal (electrical) heat production of 100 W, simulating human metabolism. The creation was covered by a cotton based textile fabric in order to get a relevant radiation emissivity of its surface. A quite even surface temperature distribution was attained.

A picture of the classroom with the person simulators is shown in figure 1, and a sketch of the set-up in figure 2. The doors to the outdoor climate simulation room were open all the time in order to have about the same temperature around the whole classroom. The two circular inlet terminals (diameter 320 mm) diffused the air all 360° between heights 435 and 830 mm above floor. The total air flow rate was 200 l/s, providing 8 l/s per person, which is in line with the recommendations for schools in Sweden. This gives an air exchange rate of 4.0 room volumes per hour. The inlet air temperature was kept at 14.5 °C; this low value was needed in order to keep the room air temperature at a reasonably low level. The two outlet terminals extracted the air at the uppermost 165 mm on the "right" wall, according to figure 2. Fluorescent lamps, developing a total power of 525 W, were hanging 510 mm below the ceiling.

In order to simulate the spreading of contaminants from a person, like allergens and bioeffluents, one of the person simulators was chosen to be the source of contamination.

Tracer gas was thus distributed along the whole length of the Contaminating Person Simulator (CPS). This was done through a tube, mounted on the CPS, and perforated in such a way that the gas flow was proportional to the local relative body area.

When studying the influence of physical activity, the "teacher" simulator was replaced by a real person (male, length 1.80 m, weight 70 kg, wearing a long-armed shirt and long trousers). This person performed intermittent walks in the class room, following the path in figure 2. Two different walking speeds were tested: "slow walk", at about 0.6 m/s , and "normal walk", at about 1.3 m/s. The "slow walk" was executed at 3 min intervals, each walk taking about 30 s to perform. The "normal walk", taking about 15 s to perform, was executed at the shorter 1 min intervals, as well as at the 3min intervals. Walk direction was changed after each walk.

As tracer gas, Sulphur heaxaflouride (SF_6) was used, 10 times diluted with air before released at the CPS. Measurements of gas concentrations were done in the outlet terminals and at eight different heights in the classroom in both positions C1 and C2, according to figure 2. To get an idea of the actual exposure of the "students" to the contaminant, gas concentrations were also measured in the "breathing" zone (1.15 m above floor level) of some of the person simulators.

In order to get reliable mean values of the concentrations, measurements were performed during about 1 h 15 min for each test case. When walking was performed, the walking procedure started about 1 hour before measurement start. At the end of each test the room air was mixed by means of two powerful fans, whereupon the mean gas concentration in the air was measured. The vertical air temperature gradient was measured in positions T1, T2 and T3 according to figure 2. In test cases involving physical activity, only position T2 was used.

Results and discussion

Figure 3 shows how the position of the Contaminating Person Simulator, CPS, influenced the Normalized Mean Concentration in the Room, NMCR; "normalized" meaning that the concentration is relative to the outlet concentration. (I.e. NMCR is the reciprocal to the often used "Contaminant Removal Effectiveness", or "Ventilation Effectiveness".) Obviously there was a strong influence of the CPS position, NMCR being lower the closer the CPS was sitting to the outlet terminals. With the CPS in position A – furthest away from the outlet – NMCR actually got higher than 1.0, which is the value one would get in a perfectly mixed system. This indicates that the contaminant had collected into high concentrations somewhere in the room, and some local measurements (not presented here) showed that it was in the upper half of the left hand side of the room (position C1) that the high concentrations could be found. Smoke visualization revealed that the major part of the thermal convection flow along the person simulators (PS) reached the ceiling, beneath which a net air flow towards the outlet was observed. Thus it seems that the upper zone was not at all well mixed, but that there were short cuts for the contaminants to the outlet, as well as contaminant collection in some areas, all depending on the CPS position.

Now to the influence of physical activity. Figure 4 shows how NMCR depended on the level of activity of the walking person. In all test cases involving activity the CPS was sitting in position C. All activity cases showed higher mean concentrations than when there was no

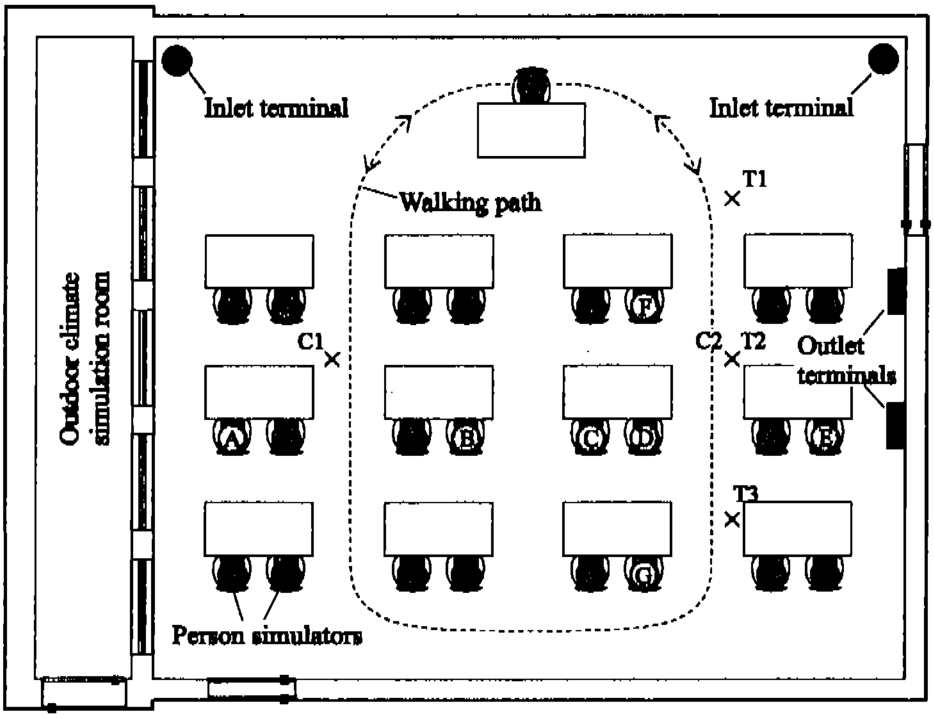

Figure 2. Sketch of the set-up in the classroom, drawn to scale.

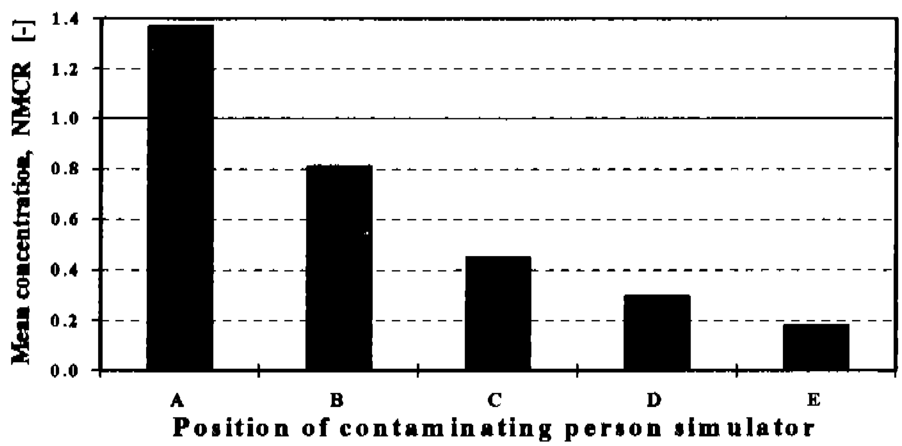

Figure 3. Normalized Mean Concentration in the Room (NMCR) for different positions of the contaminating person simulator.

activity in the room. The shorter walking intervals, 1 min, caused higher concentration, whereas the speed to perform a walk doesn't seem to mean so much for the NMCR. It is noticeable that even at the relatively high activity level of one walk around the room every minute, NMCR stayed well below 1.0, indicating a still existing displacement effect.

The vertical concentration profiles are shown in figure 5. Again the values are normalized with the outlet concentration. The reference case "perfectly mixed room air" would thus cause a 1.0-line-profile. Clearly there was a significant difference in concentration distribution between the two measuring positions, with the highest values found in position C2. This indicates substantial horizontal variances in concentration profiles within the room, again showing that the two-zone model doesn't apply very well to cases like this. The higher the activity, the more the contaminants were spread to the otherwise quite clean zone around C1, whereas around

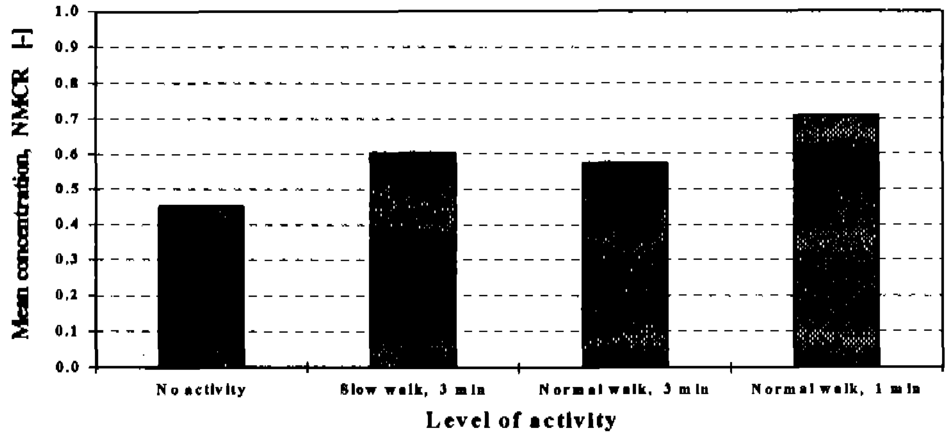

Figure 4. Normalized Mean Concentration in the Room (NMCR) for different levels of activity. Contaminant in position C. Concentrations relative to outlet.

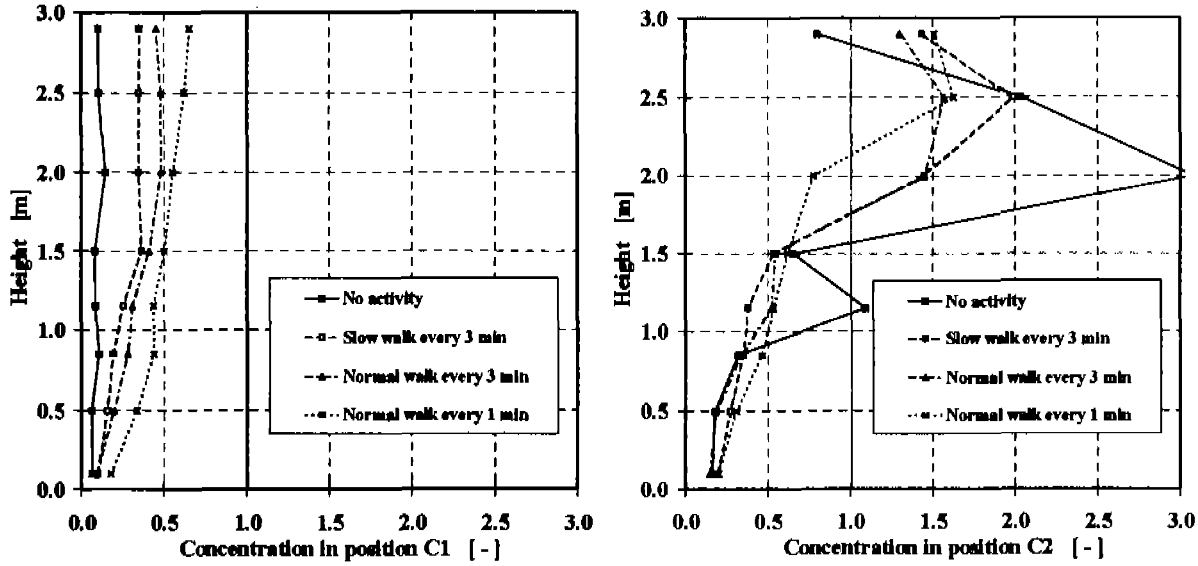

Figure 5. Vertical concentration profiles in position C1 (left) and position C2 (right) at different levels of activity. Contaminant in position C. Concentrations relative to outlet.

C2 the high concentrations in the upper part of the room decreased with increased activity.

Figure 6 presents the influence of the activity on contaminant exposure in the breathing zone of four of the person simulators. Lowest exposure was found in position A, which is in accordance with the findings in figure 5, showing low concentrations in this part of the room. All PSs were exposed to higher concentrations the more frequent the walks through the room were, but it is only in position D that we can see a marked impact of walking *speed.* All values are however well below 1.0, implying that all PSs are exposed to cleaner air than they would if the room had been equipped with mixing ventilation. That holds in fact even for the PS in position D, which was sitting next to the CPS.

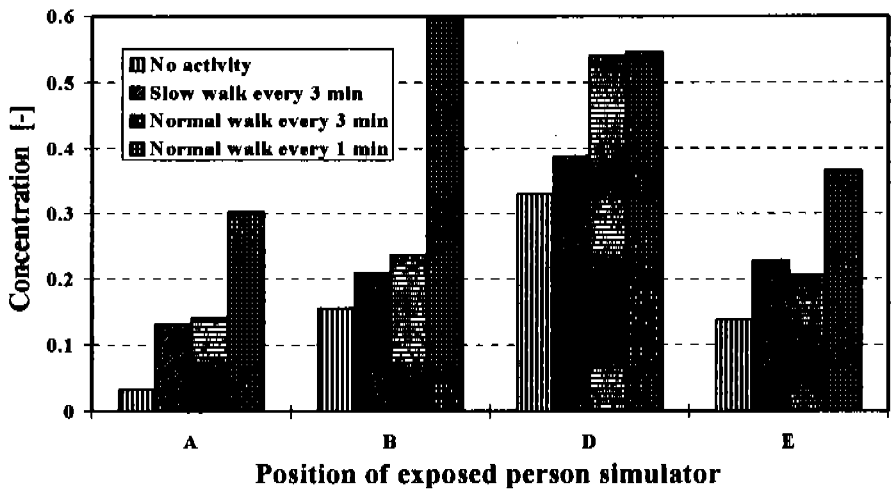

Figure 6. Exposure of person simulators to contaminant from position C at different levels of activity. Concentrations relative to outlet.

Does the supply air then reach also the persons at the back row? In figure 7 the exposure of three PSs, sitting in the same column, to contaminants from position C are given. In these positions also the mean age of air was measured, using the concentration decay method. In this case there was no physical activity in the room. Contrary of what one might expect, the PS at the back row (G) didn't get worse air than the others – it actually got better! The mean age of air differs only marginally between the three positions, meaning that it took about the same time for the supply air to reach each of the PS. However, the exposure to the contaminant was higher the closer to the inlet terminal the PS was sitting. This phenomenon can be explained by studying the air movements in the lower part of the room in more detail. The arrows in figure 7 show the flow pattern which was observed using smoke. The supply air was seen to flow rather quickly along the floor to all parts of the room. Not so much seemed to be dragged up by convection currents at the feet of the PSs, especially not at the front row, where the speed of the air was highest. The supply air then bounced against the rear wall, and flowed back towards the front wall, forming a pretty thick counter-flow. Almost all the air in this counter-flow then seemed to be captured by the convection currents along the person simulators. Most of these convection currents along the PS bodies seemed to reach the head of the PS, and then follow the plume towards the ceiling. But parts of the flow along the legs were obstructed by the table and instead seemed to join the counter-flow, as sketched in figure 7.

Thus, much – maybe the main part – of the air that reaches the breathing zone comes from the counter-flow from the rear part of the room. On its way the counter-flow collects possible contaminants from the lower part of the "student's" bodies. This line of reasoning explains the air quality values presented in figure 7. Similar concentration measurements were performed also in the column of position E, giving a similar result, although the differences were smaller.

In a separate test case, where 32 person simulators were used and provided with air corresponding to 5 l/s per person through only one displacement terminal, smoke visualization revealed that also in this case the supply air was spread over the whole floor, and bouncing at the back wall. The study by [3] also confirms that fresh air is found over the whole floor area in a displacement ventilated classroom, and that the efficiency of the system is good.

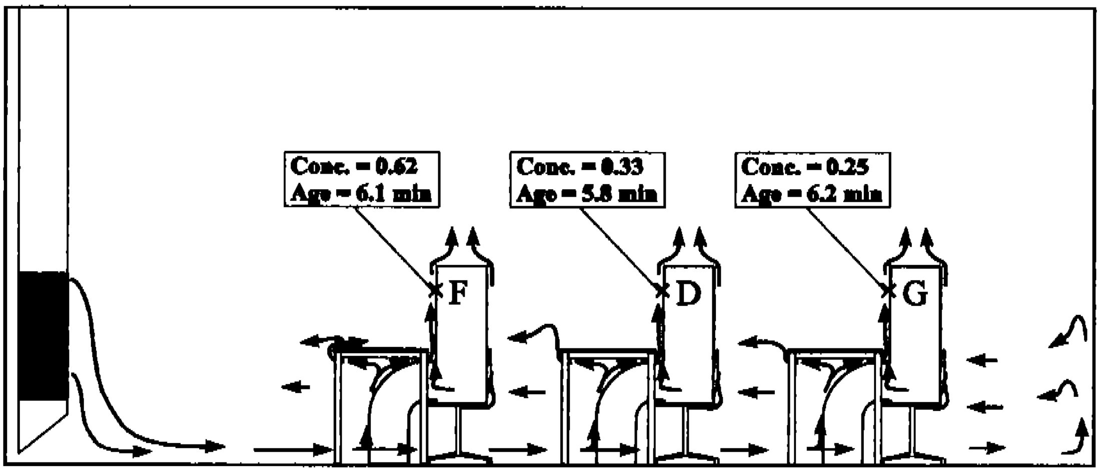

Figure 7. Sketch of the air flow pattern in the lower part of the room. Exposure in position F,D and G to contaminants from position C are given (concentrations relative to outlet). Also the mean age of air is indicated. Nominal time constant: 15.1 min.

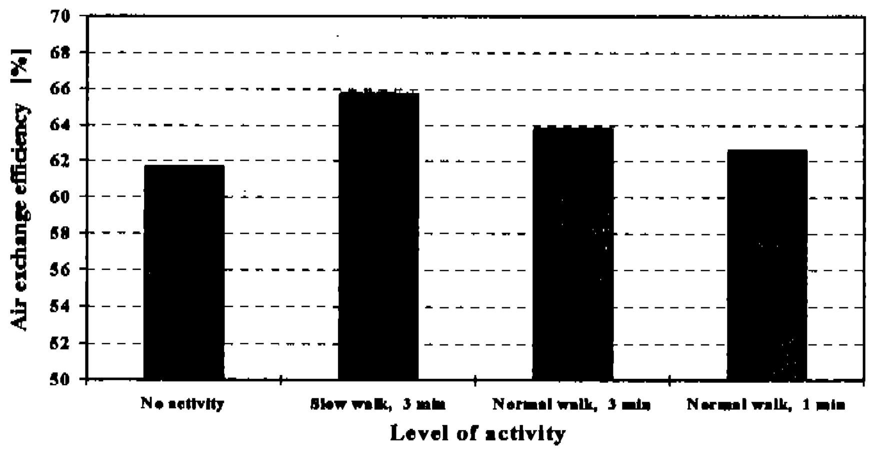

Figure 8. Air exchange efficiency for different levels of activity.

Also the air exchange efficiency in the classroom was measured (using the concentration decay method) for the four different levels of activity. The result is shown in figure8. All cases show values higher than 50 %, indicating a displacement effect. It may be a bit surprising to see that all levels of activity caused somewhat better efficiency than when there was no activity. This phenomenon, that some activity in a displacement ventilated room can cause better efficiency values, have earlier been reported in [1] and [2]. It seems like movements in the lower part of the room disturb the upwards directed convection currents along heat sources, such that those currents – of relatively "young" air – are distributed in the lower zone of the room, instead of contributing to the strong thermal plumes which mix the air in the upper zone.

The temperature gradient in the occupied zone was quite high, see figure 9. In all test cases the temperature difference between heights 0.1 and 1.1 m exceeded the ISO7730-standard value of 3.0 °C [4], warning us about thermal comfort problems. The activity tended to decrease the gradient, but only the highest activity level caused a change of any note. One should bear in mind that all measurements presented here were executed under practically steady-state conditions, and it is certainly doubtful whether this condition ever is reached in a populated classroom in practice, due to heat accumulation in materials. In reality the temperature gradient

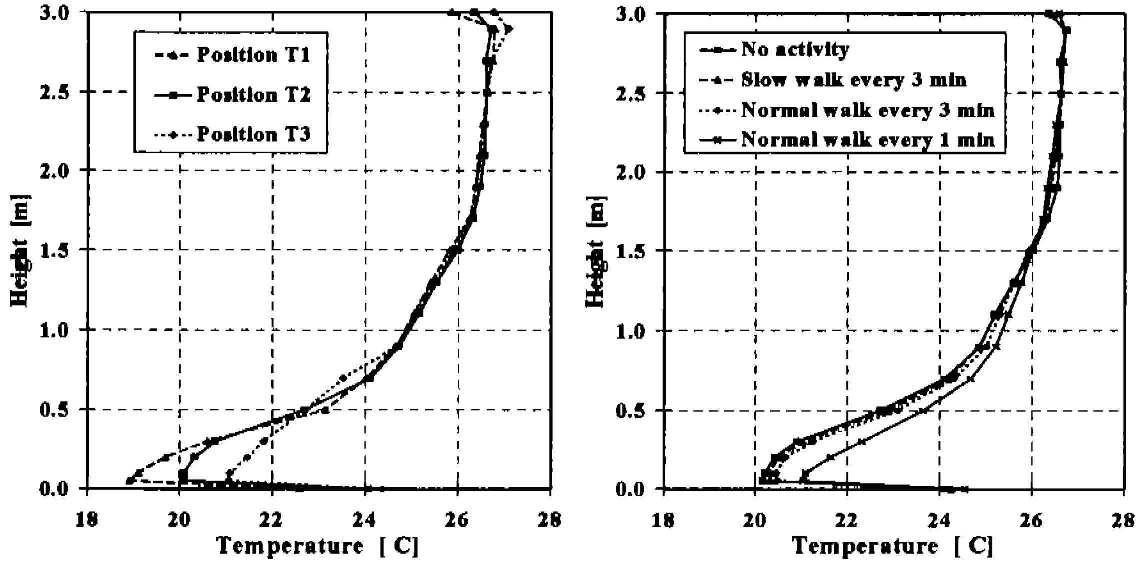

Figure 9. Temperature profiles at three positions (left) and at different activity levels (right)

might be lower than presented in figure 9, making the thermal comfort higher, but maybe also making the efficiency values of the displacement ventilation system more affected by physical activity. A dynamic case is definitely more difficult to investigate, but is an advisable subject for future research.

Conclusions

In a large, displacement ventilated and densely populated room, the spreading of contaminants from a person seems to be strongly dependent on the position of the person. The closer the contaminating person sits to the outlet terminal(s), the less of his/hers contaminants are spread in the room. People sitting furthest away from the air supply might in fact get the best air because a large portion of the air that reaches the breathing zone has first been bouncing against the back wall.

Physical activity, produced by a walking person, tends to increase the concentration of contaminants emitted from people in the room, whereas the air exchange efficiency actually can benefit from it. At all levels of activity tested in this study the displacement ventilation system provided significantly better air quality than a mixing system would.

The temperature gradient in the occupied zone was rather high during these steady-state experiments, and it was only marginally affected by the movements of a person.

References

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[4]International Standard ISO 7730, Moderate thermal environments – determination of the PMV and PPD indices and specification of the conditions for thermal comfort, International Organization for standardization, Geneva, Switzerland, 1994.