Efficiency of different ventilation concepts in classrooms

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ABSTRACT

The productivity of occupants in classrooms depends strongly on the indoor air quality and the thermal comfort. Three ventilation concepts with different arrangements of supply and exhaust openings are presented as solutions in this study. The different ventilation concepts which are mixing- and displacement ventilation are evaluated by different criteria in particular by their ventilation efficiency. A typical classroom with occupants which are defined as dummies is used as a virtual room. The investigations are realised with full–scale numerical modelling under Computational Fluid Dynamics (CFD) method and validated experimentally.

The results demonstrate on the one side that the comparison of experimental and simulation results show rather good accordance; on the other side that both concepts satisfy the demands of thermal comfort and indoor air quality in the occupied zone of the room. With the same air change rate the ventilation system provides better ventilation efficiency.

1. INTRODUCTION

A good learning environment, i.e. a room with thermal comfort and good indoor air quality, can insure students' high concentration for learning. Research (Ribic, 2008) shows the relationship between CO_2 concentration and ability of learning. Therefore, ventilation through windows or mechanical means, or both, is necessary for the students in classroom.

In this investigation mechanical ventilation with mixing – and displacement ventilation concepts are focussed. They are realized by the arrangement of air supply opening and exhaust. Three variants are performed with numerical simulations for the cases in extreme summer and winter conditions. The variants have the same exhaust but different air inlet form and location. Variant 1 is mixing ventilation with two slit air inlets in the ceiling. Variant 2 is displacement ventilation with two standing air inlets in the corner. Variant 3 is also displacement ventilation but with air inlet on the bottom of one of the room's walls. The CFD–simulation is validated experimentally just for variant 2 in extreme summer. The contaminants in the study are represented by CO_2 from the occupants.

The results demonstrate that all concepts fulfil the demands of comfort and indoor air quality in the classroom, but the ventilation system provides an environment that is slightly too warm in the summer (PMV is a little above 1) and a little too cool in winter (PMV is from -1 to 0). A displacement ventilation system can provide better ventilation efficiency and keep better IAQ for the occupants concerning contaminants in the room at the same air change rate.

2. MODEL AND BOUNDARY CONDITIONS

The defined classroom with the different ventilation systems is shown in figure 1. The size of the room is: 9 m in length, 4 m in width and 3 m in height. The windows are located in southwest orientation; the door is opposite the windows. Three radiators are arranged under the windows. There are 25 cylindrical dummies (1.16 m x ∅ 0.3 m) as occupants standing behind the desks. One dummy as a teacher stands in the front of the room, the other 24 dummies as students stand opposite. The exhaust (1 m x 0.25m) is arranged directly above the door. The slit air inlet (8 m x 0.015m) in variant 1 is defined in the ceiling; the slit openings are spread to two rows. The supply openings (1.5 m x ∅ 1 m with ¼ circle) in variant 2 are located at the two corners opposite the windows and the opening (5 m x 0.5 m) in variant 3 is in the wall opposite the windows as well. The grey zone in figure 1 shows the occupied zone according to DIN EN 13779. The distance from side walls is 0.6 m and from ceiling 1 m. There are no distances from the front and rear wall as well as from the floor. The correspondent names of components are demonstrated in figure 1, as well.

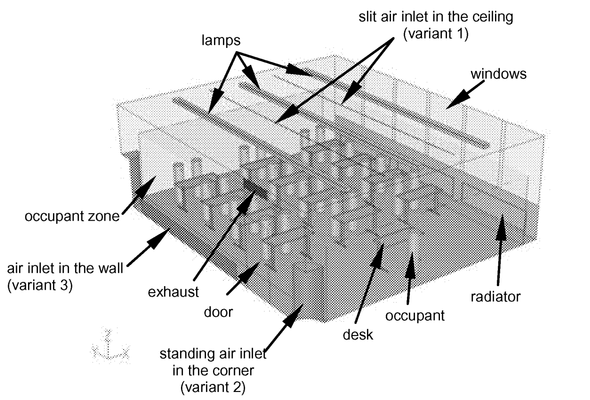

Figure 1: Classroom model for mixing- and displacement ventilation

The commercial software FLUENT serves as a tool for the numerical simulations. RNG $k-\varepsilon$ turbulence model is defined for airflow in the room. The simulation of CO_2 and humidity is done by species model in Fluent. The grids have about 1.3 million cells (hexahedron and tetrahedron). The simulations run under steady – state conditions.

The simulations are valid for cases in extreme summer and winter conditions. There are no heating loads not only for the cases in summer, but also in winter. The cooling loads come from occupants and lamps; they are calculated for the whole year under dynamic simulation with the software TRNSYS16; the critical moments in extreme summer and winter are chosen for the steady-state CFD-simulations. The cooling loads in extreme winter are defined at -4 °C outside temperature. Every one of the three lightning rows emits 190 W. Each occupant emits 65 W of sensible heat (i.e. 1.1 met per occupant) and gives 60 g/h of dampness and 0.02 m^3/h CO_2 from breathing to the environment. The conditions of comfort are defined according to the standard DIN EN ISO7730. The room set-temperature is defined to 26 °C in an extreme summer and 20 °C in an extreme winter, and relative humidity at 55% in both seasons. For boundary conditions for supply air see table 1.

Table 1: Boundary conditions for supply air

	Mixing ventilation with slit inlet in the ceiling (variant1)	displacement ventilation with standing air inlet in the corner (variant2)	displacement ventilation with air inlet in the wall (variant3)
summer			
set-temperature [°C]	26	26	26
supply air temperature [°C]	21	23	23
under - temperature [K]	5	3	3
absolute humidity of supply air [g/Kg]	10.80	11.20	11.20
inlet velocity [m/s]	4.1	0.21	0.2
winter			
	Mixing ventilation with slit inlet in the ceiling (variant1)	displacement ventilation with standing air inlet in the corner (variant2)	displacement ventilation with air inlet in the wall (variant3)
set-temperature [°C]	20	20	20
supply air temperature [°C]	15	17	17
under - temperature [K]	5	3	3
absolute humidity of supply air [g/Kg]	6.40	7.00	7.00
inlet velocity [m/s]	2.30	0.12	0.11

3. EXPERIMENT AND VALIDATION

The experiment is carried out in an airflow experiment cabinet. Because of the dimensions of the cabinet, the experiment is performed for only one half of the room based on its symmetry: see figure 2.

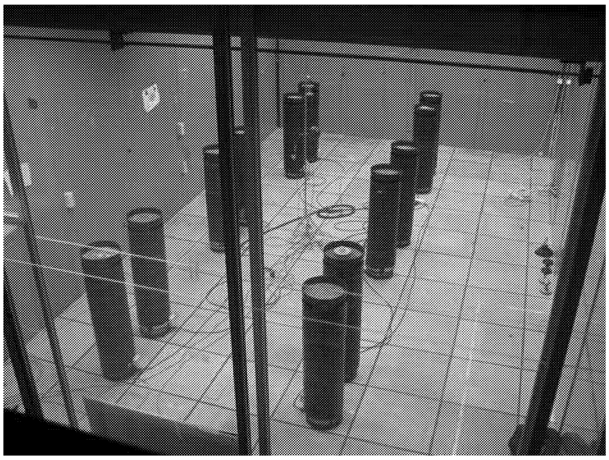

Figure 2: Validation in an airflow experiment cabinet

The validation is determined by the following measuring points at axis A and B; the labels from axis I to V are valid for the estimation of simulation results only: see figure 3.

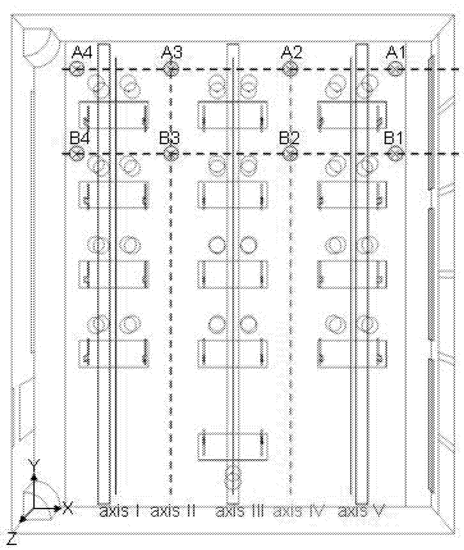

Figure 3: Measuring points for validation and estimation of ventilation concepts

Temperature and velocity are measured from floor to ceiling and compared with the results at the same points of the simulation of variant 2. The validation shows a good accordance of temperatures and velocities of experiment and simulation, in particular 1.1 m above the floor. Deviations can be recognised near the floor: see figure 4.

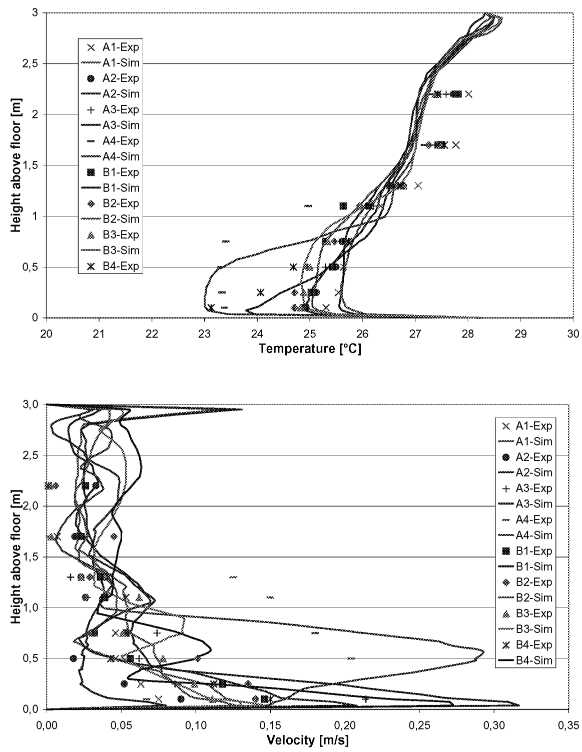

Figure 4: Validation of simulation for displacement ventilation (temperatures and velocities)

4. RESULTS

4.1 Airflow pattern and comfort estimation

Figure 5 as well as figure 6 display path lines of draught rating for the ventilation concepts with extraordinary summer and winter weather. The scale is between 0 and 20 percent. Draught rating shows how high the percentage of persons who are not satisfied with the environment due to draught around them is. The draught rating depends on the local temperature, the local mean velocity and the local turbulent intensity according to prEN 13779. The arrangement of exhaust in the room and asymmetric allocation of thermal loads from the

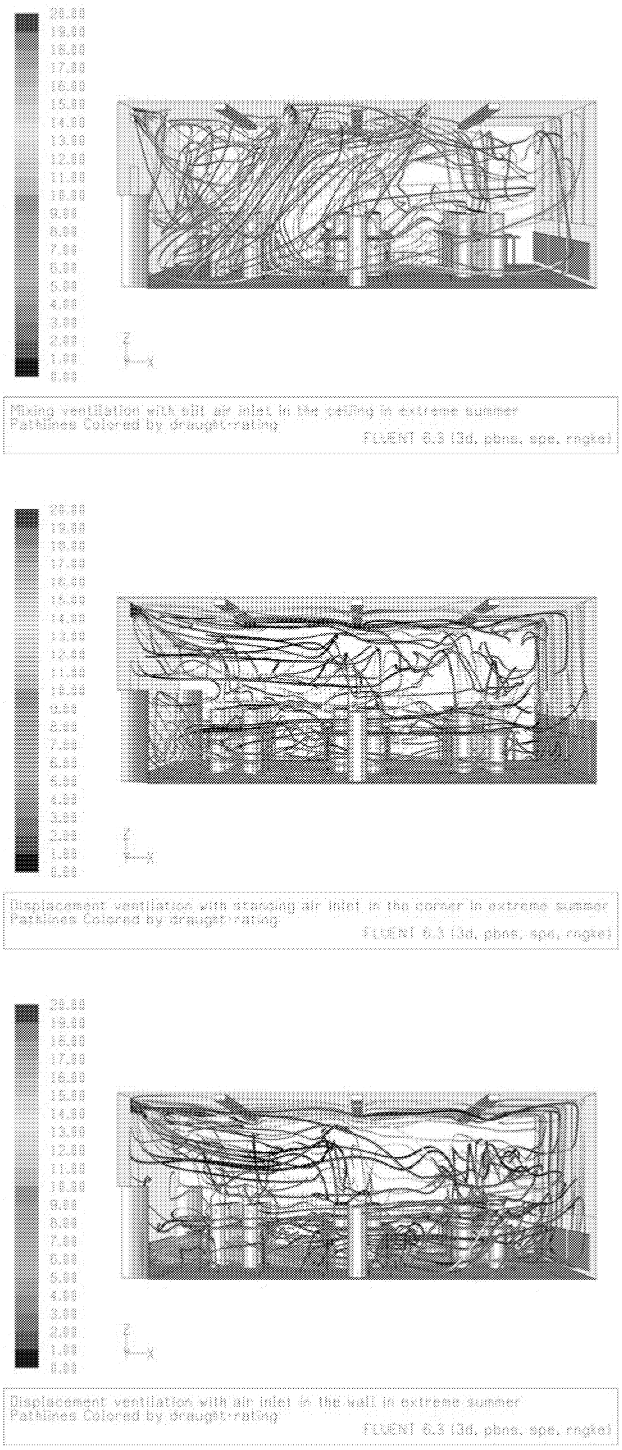

Figure 5: Path lines in the mixing (top) and displacement (middle and bottom) ventilation in extreme summer

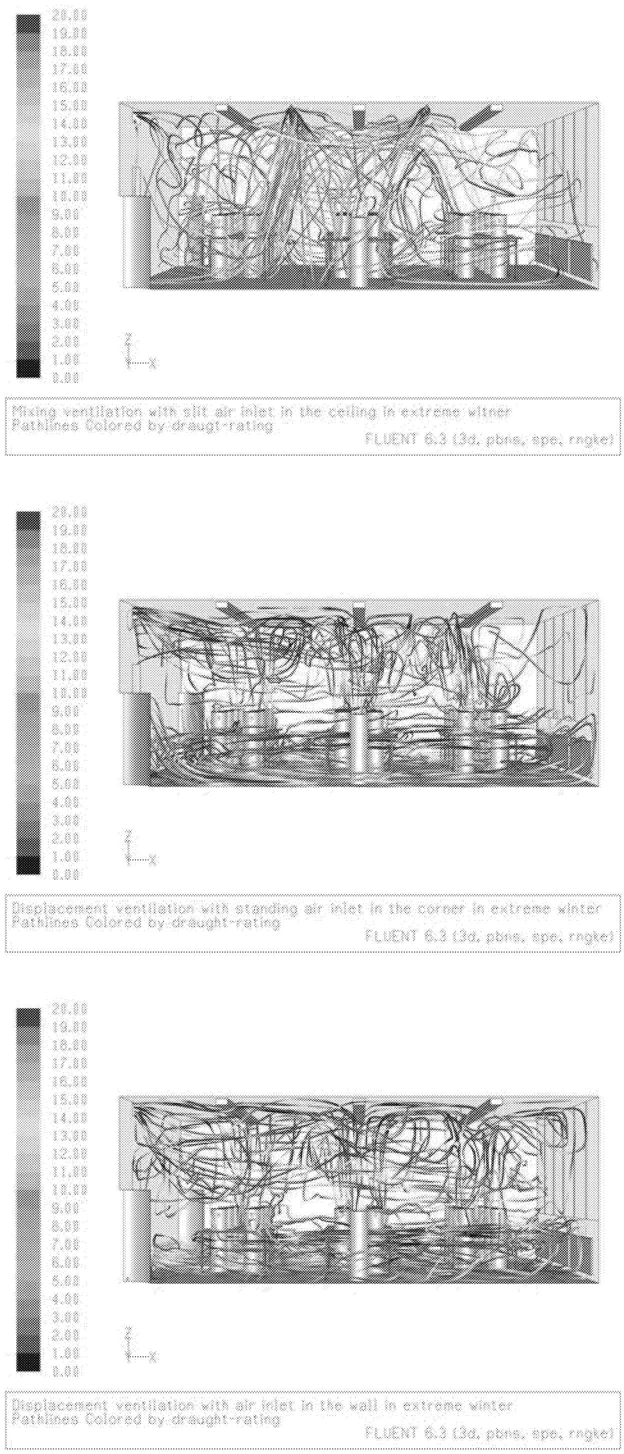

Figure 6: Path lines in the mixing (top) and displacement (middle and bottom) ventilation in extreme winter

windows cause an air roll (anti-clockwise) in the mixing ventilation (variant 1). The displacement ventilation has a different airflow mechanism.

In spite of different air inlets of variant 2 and 3, the supply air enters the room through the supply opening in the left side of the room flows towards the opposite wall and then returns to the occupants. From this point most of the air flows in a vertical direction and then under the ceiling sweeps towards the exhaust. There are similar phenomena of airflow patterns in winter and in summer. But the mixing ventilation system in winter supplies an air roll in the room which is weaker than in summer. Three cases in this study can provide occupants basic thermal comfort in extreme summer and winter, see table 2. The results show conditions to be almost too warm in summer and vice versa in winter. Because of the arrangements of the air inlet and exhaust, there is a risk of draught for the occupants who are near the air inlet in displacement ventilation system in rooms, in particular for variant 3.

Table 2: Mean values of thermal comfort in the classroom

	summer		
	Mixing ventilation with slit inlet in the ceiling (variant1)	displacement ventilation with standing air inlet in the corner (variant2)	displacement ventilation with air inlet in the wall (variant3)
temperature in room[°C]	26	26	26.1
velocity [m/s]	0.12	0.07	0.05
relative humidity [%]	54	55	55
PMV	1.00	1.10	1.20
PPD [%]	29	33	34
	winter		
	Mixing ventilation with slit inlet in the ceiling (variant1)	displacement ventilation with standing air inlet in the corner (variant2)	displacement ventilation with air inlet in the wall (variant3)
temperature in room[°C]	20	20.5	20.6
velocity [m/s]	0.11	0.05	0.04
relative humidity [%]	54	55	55
PMV	-0.80	-0.60	-0.60
PPD [%]	19	14	14

4.2 CO_2 distribution and estimation of ventilation efficiency

CO_2 concentration is an important indicator of indoor air quality in occupied rooms. It should be less than 1,000 ppm according to Pettenkofer. Figures 7 and 8 (top: mixing ventilation, middle and bottom: displacement ventilation) display the distribution of the CO_2 concentration at the defined points from floor to ceiling. The displacement ventilation can provide

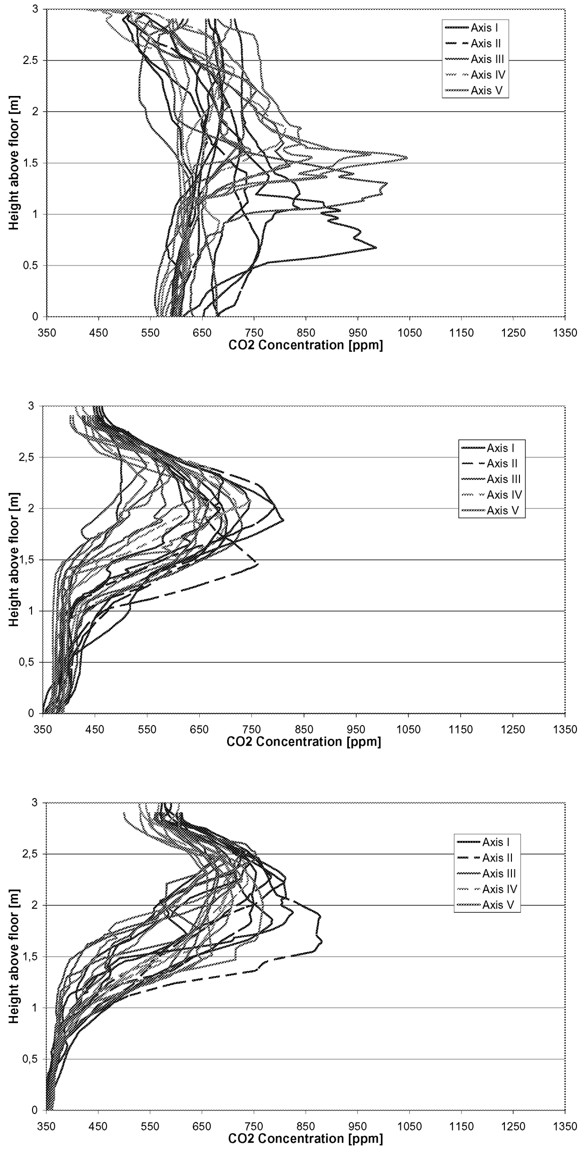

Figure 7: Distribution of CO_2 concentration in extreme summer.

homogenous CO_2 concentration distribution almost all over in the room and fulfil the demands. The mixing ventilation supplies a heterogeneous CO_2 concentration distribution. The CO_2 concentration can be higher than 1,000 ppm near the windows, for example. The ventilation efficiency in such locations is insufficient.

Potential terms for estimation of ventilation systems are the contaminant load, air change efficiency, ventilation effectiveness as well as ventilation efficiency (Raatschen, 1988). The concentration of CO_2 in the supply air is set to zero. The results are shown by bar diagrams in figure 9 (top: summer; bottom: winter).

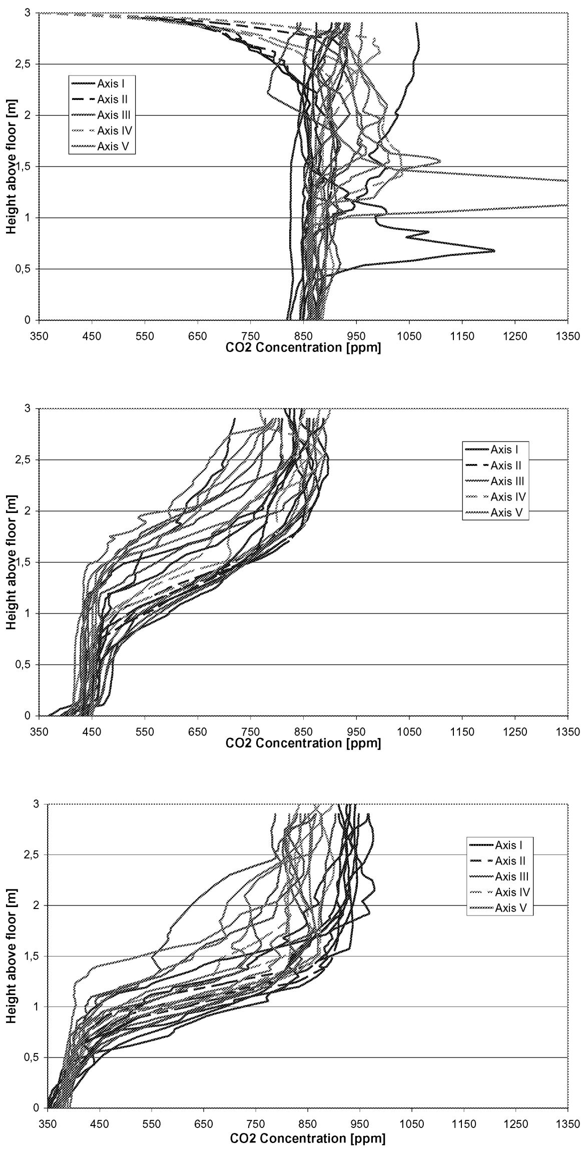

Figure 8: Distribution of CO_2 concentration in extreme winter.

5. CONCLUSIONS

The three ventilation concepts in this investigation can basically provide a thermal comfortable environment and sufficient indoor air quality for students and teacher. The local thermal comfort can not be guaranteed completely due to the location of air inlet for the displacement ventilation as well as the under-temperature of supply air for the mixing

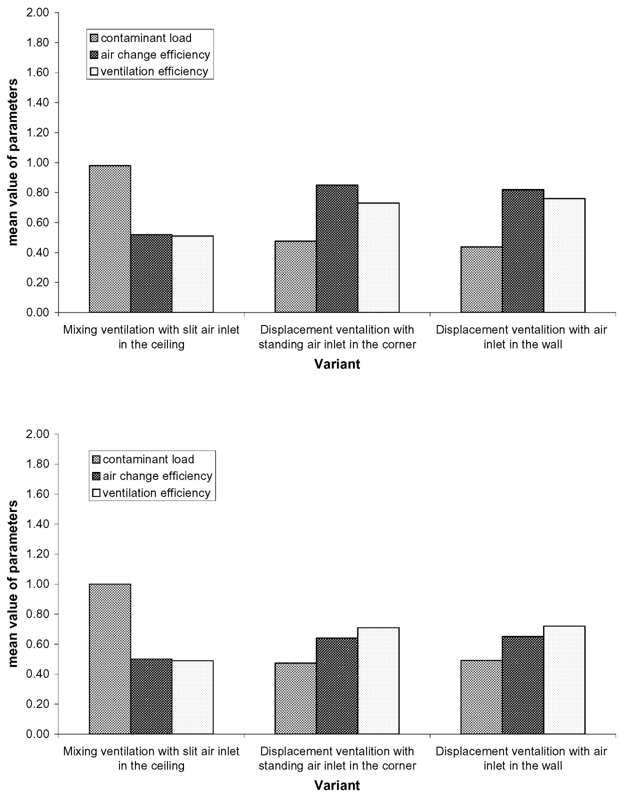

Figure 9: Ventilation efficiency in extreme summer (top) and winter (bottom)

ventilation (risk of draught). The results show that the displacement ventilation can achieve higher ventilation efficiency than mixing ventilation in summer as well as in winter.

REFERENCE

Raatschen, Willigert (1988).Was ist Lüfungseffektiviät?. KI 5, pp. 226-231; KI 6, pp. 291-296; KI 7-8, pp. 331-334.

Ribic, Werner (2008). Nachweis des Zusammenhanges zwischen Leistungsfähigkeit und Luftqualität. GI Gesundheits-Ingenieur, Heft 2, pp. 88-91.