Air distribution in a classroom

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One main factor for inadequate indoor air quality in classrooms is the design of air distribution. This paper presents comparison of the indoor air quality in the classroom in summer and winter conditions with most used mechanical air distribution systems. Indoor air quality in the occupied zone is best with displacement ventilation. Air distribution with supply air grille gives uniform conditions, but it can cause problems due to too high velocities in some locations. Supply air jet from perforated duct diffuser and from ceiling diffuser tends to be carried along thermal plumes from the heat loads.

The performance of four typical air distribution methods in winter and summer conditions with different occupancy ratio was studied in a mock-up classroom (Kosonen and Mustakallio 2010) and was visualized with CFD- simulations (Mustakallio and Kosonen 2011).

The measured mock-up room (6.0 m × 4.4 m × 3.3 m (H)) was half of a actual classroom (floor area 6 × 10 m²). The simulated window size was 4.4 m × 1.4 m (H). The air distribution was identified at three different load conditions: summer conditions with maximum occupancy (cooling load of 54 W/m²) and partly occupied (cooling load of 40 W/m²) and winter conditions with partly occupied room (heating demand of 38 W/m²). The room was ventilated at 6 l/s per person in all cases. In the winter condition, an underneath radiator was introduced to prevent draft risk of cold window surface. The heat balance and breakdown of the loads in the measurement cases are presented in **Table 1**.

Utilizing dynamic energy simulations, room air temperatures in winter and summer are set to be corresponding average conditions in Scandinavian classrooms. In laboratory conditions, heat losses were supplemented by heat losses through structures, if necessary, to attain the room air temperature required.

The performance of four typical air distribution methods was studied: a corridor-wall grille, a ceiling diffuser in the middle of the ceiling, a perforated duct diffuser in the middle of the ceiling, and two displacement ventilation units in the floor corners (**Fig. 1**). The supply units were selected based on the throw pattern analysis. The supply airflow rate was 90 l/s (6 l/s per person) in all cases (half classroom). The supply air temperatures were 17°C and 18°C in summer and winter cases respectively. The room air temperatures were 26°C and 24°C in summer case with full and half occupancy respectively. In winter conditions, the room air temperature was set to be 21°C.

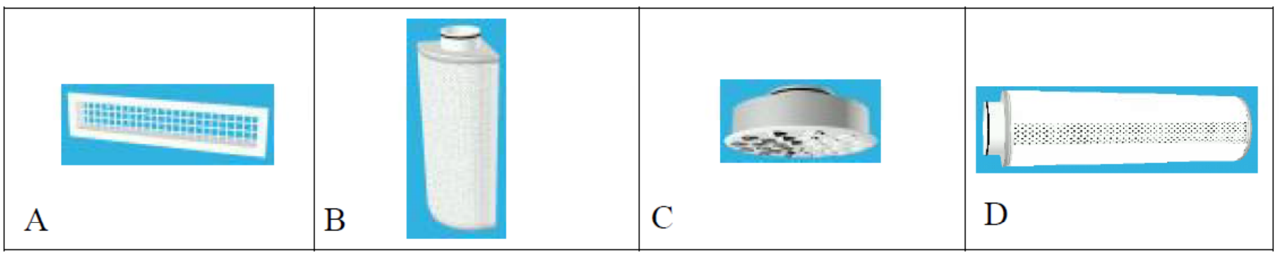

Figure 1. Air distribution schemes: A) Wall grille, B) Displacement ventilation, C) Multi-nozzle ceiling diffuser and D) Perforated duct diffuser.

Air velocity and temperatures were measured at 24 pole locations and at 7 heights (0.1, 0.5, 0.9, 1.3, 1.8, 2.4 and 3.1 m above the floor) at each location, i.e. altogether in 168 points. The classroom and the measurement pole locations are shown in **Fig. 2**.

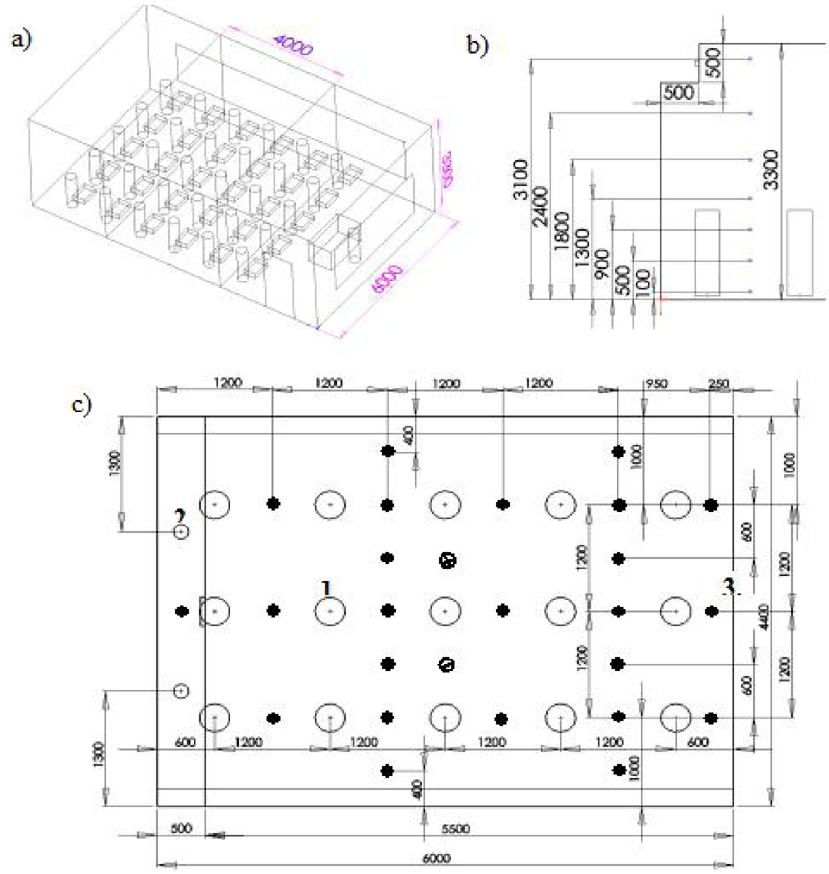

Figure 2. a) The classroom geometry with heat load simulated; b) Measurement pole locations: ● = pole location, ⊗ = black ball temperature at 1.3m from floor, ⊖ room temperature at 1.3 m from floor, 1.=heated cylinder representing occupant heat load, 2.=exhaust valve and 3.=simulation window.

Smoke and CFD- visualizations of air distribution in full occupancy summer cases are shown in **Figure 3**. Thermal plumes did not have a significant effect of the performance of a wall- grille: the momentum flux of a wall-grille was strong enough to attain the other side of room. Also, air spread effectively over the whole occupied zone with the low velocity units, whereas supply air from the ceiling diffuser tends to be carried along thermal plumes from heat sources (in the winter case without window heat load and with half occupancy flow pattern was more uniformly). A perforated duct diffuser had a tendency to create unstable flow conditions and varied loads can change unexpectedly thrown pattern.

High velocities (over 0.3 m/s) over the occupied zone were measured in all conditions with a wall-grill. The highest velocities (above 0.2 m/s) were measured near the window (0.25 m distance). In all conditions velocity higher than 0.2 m/s was also measured near the floor, 0.1 m height at distance as far as 3.6 m from the window. A displacement ventilation concept was not sensitive to load variation and air velocities were very low (<0.15 m/s) except measurement points close to the corner-installed supply unit. With a ceiling diffuser, air velocities were reasonable low in all cases (0.19–0.23 m/s). With a perforated duct diffuser relatively high velocity (0.15 – 0.2 m/s) was measured near the floor (0.1 m height). In the two summer conditions the velocity was above 0.2 m/s (up to 0.31 m/s with

Table 1. Heat balance and the breakdown of the loads in the mock-up classroom section.

Heat loads and heat losses of the simulated classroom (half size of the actual classroom)	**Summer Full Occupancy**	**Summer Half Occupancy**	**Winter Half Occupancy**
Room air temperature	26°C	24°C	21°C
Occupants - 58 W/person (total heat load)	15 (870 W)	7 (406 W)	7 (406 W)
Lighting 15 W/m²	360 W	360 W	360 W
Solar load or heat loss from window (surface temperature of window)	197 W (30°C)	296 W (30°C)	–448 W (11°C)
Power of a radiator underneath window	0 W	0 W	250 W
Total heat gains	**1427 W**	**1062 W**	**1016 W**
Supply airflow rate 90 l/s (supply temperature)	–972 W (17°C)	–756 W (17°C)	–324 W (18°C)
Heat loss through structures	–455 W	–306 W	–244 W
Total heat losses	**–1427 W**	**–1062W**	**–1016 W**

full occupancy) close to the floor for the locations 3.6 and 4.8 m from the window, i.e. the increment of heat gain increased air velocities. This depicts more unstable performance with a perforated duct diffuser when higher heat gains are introduced in the classroom.

Air distribution with corridor wall-grille gave high velocities in all load conditions. In winter conditions, air velocities even raised close to the window. In principle, the thrown length could be optimized for winter conditions and thus get lower velocities close to the window workplaces e.g. by selected larger wall-grille. This increases draught risk in summer conditions.

Supply air jet from ceiling diffuser tended to be carried along thermal plumes from the heat loads during summer times. In winter when there was no the effect of window plume, air distribution was more uniform. The function of ceiling diffuser concept is quite appropriate in varied load conditions.

With a perforated duct diffuser, the performance is quite unstable and sensitive when higher heat gains exit. In those conditions, supply air could unexpectedly drop down causing increased draught risk in certain work places.

In mixing ventilation concepts, load conditions have a significant effect on air distribution and when the air distribution strategy is designed the system performance should be analysed in different conditions. In design phase without using CFD- simulation or laboratory mock-ups, it is not possible to analyse the interaction of convection flows and jets.

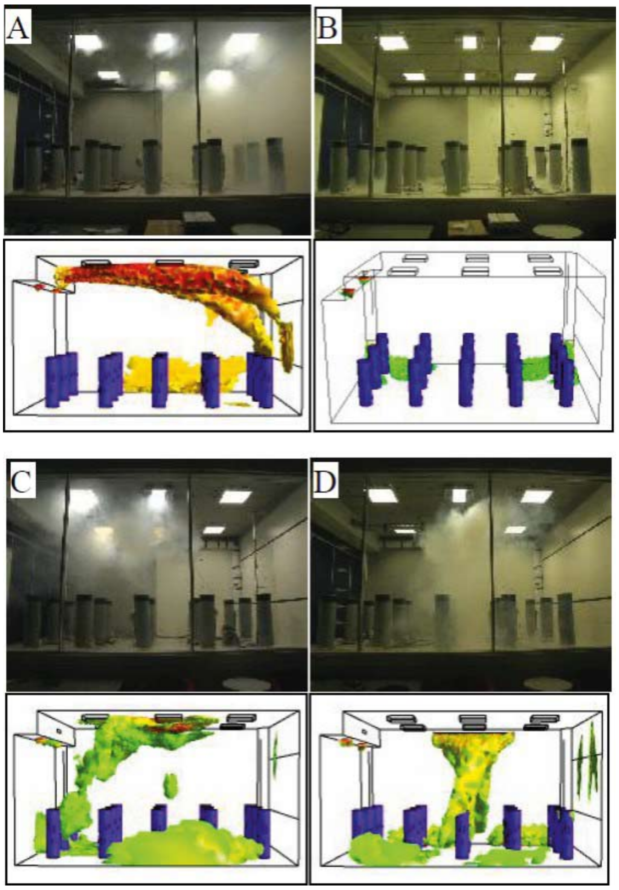

Figure 3. Visualization of air distribution smoke /half classroom) and CFD (in cooling case with full occupancy. Supply air units: a) a wall-grille, b) displacement ventilation with low velocity units, c) a ceiling diffuser and d) a perforated duct diffuser.

Conclusions

The quality of the indoor climate and thermal conditions in schools has been found to be poor in a number of surveys. To analyse thermal comfort conditions in a classroom, measurements were conducted in laboratory conditions. The performance of four typical air distribution methods was studied in a mock-up classroom with different load conditions. The measured air distribution methods were: a corridor-wall grille, a ceiling diffuser, a perforated-duct diffuser and a displacement ventilation concept. From the tested concepts, displacement ventilation is the least sensitive for different load conditions of all studied concepts. Using a ceiling diffuser, air velocities were reasonable low in all cases. Together with displacement ventilation, ceiling diffuser is the other recommended solution for classrooms. A wall grille gave high velocities in both summer and winter conditions. With a perforated duct diffuser, air distribution is quite unstable causing increased draft risk in some load conditions. The performance of a wall-grille and a perforated duct diffuser is sensitive for strength and location of heat gains. ■

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