Ventilation in Classroom: a Case-Study of the Performance of Different Air Distribution Methods

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SUMMARY

The quality of the indoor climate and thermal conditions in schools has been found to be poor in a number of surveys. To analyze thermal comfort conditions in classrooms, the 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 using low velocity supply at low level. From the tested concepts, displacement ventilation was least of all sensitive for different load conditions. The wall grille supply concept gave high velocities in the occupied zone in both summer and winter conditions. During summer time, thermal plumes had an influence on air distribution of a ceiling diffuser. In winter, air distribution was uniform. Using a perforated duct diffuser, the air distribution was quite unstable causing increased draft risk in some load conditions.

INTRODUCTION

The quality of the indoor climate in schools has been found to be poor in a number of surveys [1, 2]. Poor indoor air quality causes an increase in symptoms and illness, and it shortens attention span, whereas good air quality can enhance children's concentration and also teachers' productivity [3]. The commonest indoor climate problems are inadequate ventilation and thermal comfort. To achieve a good indoor climate, an adequate airflow should be used and the functionality of air distribution should be analyzed to guarantee the performance.

Carbon dioxide concentrations are often used as a substitute of the outdoor airflow rate per occupant. IAQ in schools is primary evaluated by CO_2- concentrations. Many international standards recommend a maximum concentration level of 1000-1200 ppm to satisfy perception criteria with respect to human bio effluents. To fulfill this target, an airflow rate of about 6 l/s per person is required. In school classrooms where the occupancy density is high (1.8-2.4 m^2/person) compared e.g. to offices (10 m^2/person), reasonably high airflow rates are required to supply in classrooms. Together with the high internal and external load variation in cold and moderate climates, it makes challenging to fulfill the requirements for sufficiently low local discomfort level predicting the percentage of dissatisfied due to draft [4].

An experimental field study of the velocities generated by typical air distribution schemes has been conducted in unloaded conditions [5]. The study indicated that the actual airflow rates were significantly lower in three classrooms out of six and room temperature controllability was poor. In the classrooms, where no internal heat gains were introduced, high air velocities were still found in the occupied zone.

The location and strength of the heat gains have a significant effect on the air flow patterns [6]. Thus when the air distribution strategy is designed, the functionality of air distribution should be analyzed in different load conditions to guarantee the performance. In this study, the performance of four typical air distribution methods was studied in a mock-up classroom. The main objective was to get a holistic view of the performance and the differences of typical air distribution schemes in both winter and summer conditions with different occupancy ratios.

METHOD

To analyze thermal comfort conditions in a classroom, the measurements were conducted in laboratory conditions at the Halton facilities. The measured mock-up room of 6.0 m x 4.4 m x 3.3 m (H) equivalent to the half of the actual classroom (normal area 6 x 10 m). The conditions in the classroom were measured in three different load situations: summer conditions with fully (cooling load of 54 W/m^2) and partly occupied (cooling load of 40 W/m^2) and winter conditions with partly occupied (heating demand of 38 W/m^2). 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 were set to be corresponding average conditions in Finnish classrooms. In laboratory conditions, heat losses were supplemented by heat losses through structures, if necessary, to attain the room air temperature required. The ventilation airflow rate was constant (6 l/s per person) in all cases. In winter conditions, an underneath radiator was introduced to prevent the draft risk of the cold window surface.

Occupants were simulated with dummies that were constructed according to the standard DIN 4715-1 [7]. The dummy was heated electrically with the power of 58 W. Moreover, the dummy used in the experiments originally had three large holes on its flank, near the top surface. In tests the holes have been blocked, since the warm air blew horizontally out of them, when there was interaction between convection flow and jets.

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 ^{o}C	24 ^{o}C	21 ^{o}C
Occupants 58 W/person (total heat load)	15 (870 W)	7 (406 W)	7 (406 W)
Lighting 15 W/m^2	360 W	360 W	360 W
Solar load or heat loss from window (surface temperature of window)	197 W (30 ^{o}C)	296 W (30 ^{o}C)	-448 W (11 ^{o}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 ^{o}C)	-756 W (17 ^{o}C)	-324 W (18 ^{o}C)
Heat loss through structures	-455 W	-306 W	-244 W
Total heat losses	**-1427 W**	**-1062W**	**-1016 W**

The performance of four typical air distribution methods was studied. The measured air distribution schemes were: a corridor-wall grille (WTS-450-100), a ceiling diffuser in the middle of the ceiling (TCV-160/A R4), a perforated duct diffuser in the middle of the ceiling (HPS-160), and two displacement ventilation units on the floor in the corners of the classroom

(2xAFQ-125). The supply units were selected based on thrown pattern contemplation in summer and winter conditions. The supply airflow rate was 90 l/s in all cases. The supply air temperatures were 17 ^{o}C and 18 ^{o}C in summer and winter cases. The room air temperatures were 26 ^{o}C and 24 ^{o}C in summer case with full and half occupancy. In winter conditions, the room air temperature was set to be 21 ^{o}C.

In the mock-up classroom, air velocity and temperatures were measured in 24 pole locations at 7 different heights (altogether 168 points). Velocity and turbulent intensity were measured with omni-directional hot sphere anemometers HT412 (accuracy +/- 0.02m/s and +/- 1 % of readings with velocities 0.05 - 1.0m/s), and temperature with PT100 sensors (accuracy +/- 0.1degC). Readings are three minutes average values. The radiant temperature was also measured in one location in the middle of the room. The air distribution with different schemes was visualized with smoke. The measured section of classroom, measurement pole locations and sensor heights are shown in Fig 1.

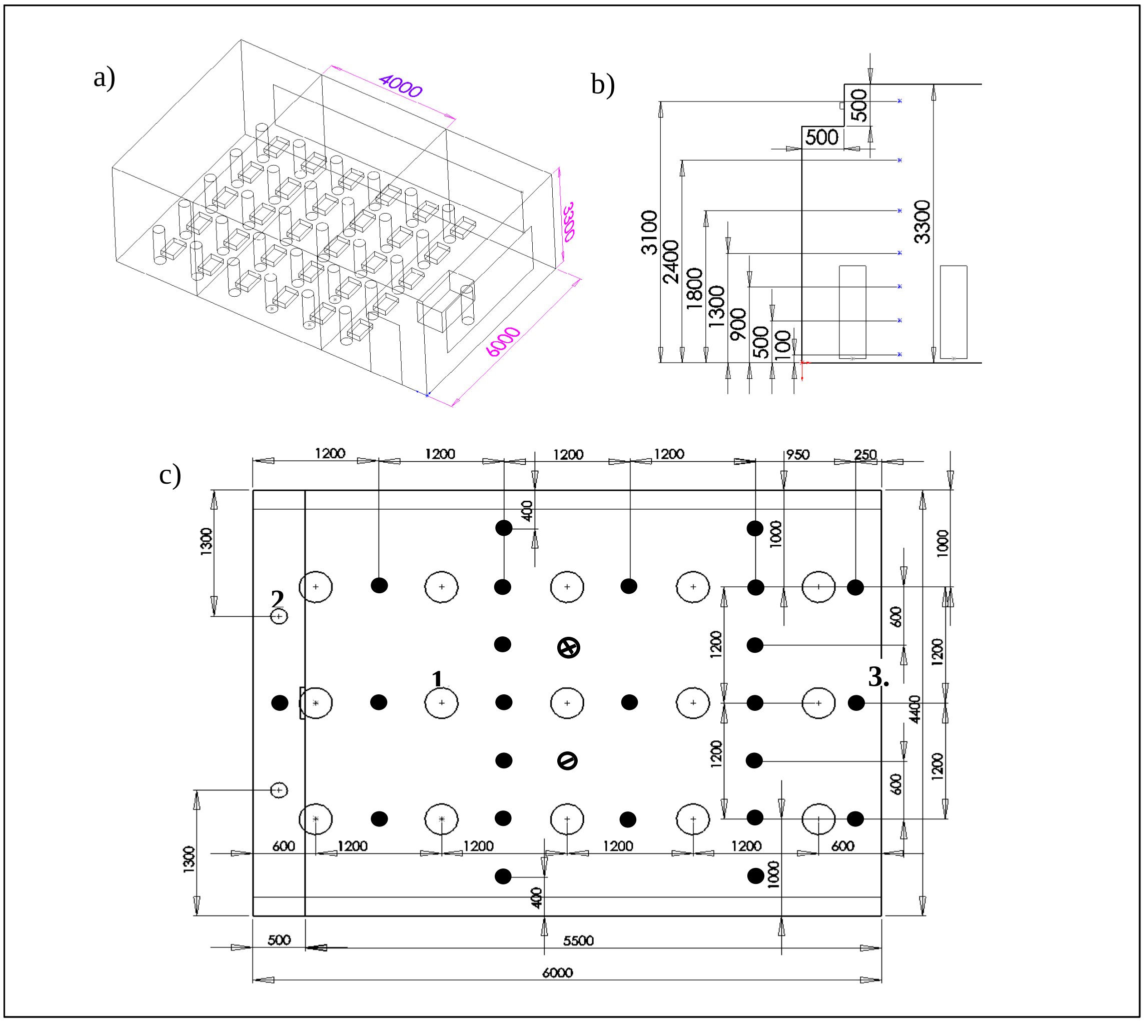

Figure 1. Panel a) Location of the measured section in whole classroom. Panel b) Measurement pole sensor heights. Panel c) Classroom geometry from top and measurement pole locations. ● = pole location, ⊗ = black ball temperature at 1.3m from floor, ⊘ room temperature at 1.3m from floor, **1.**=heated cylinder representing occupant heat load, **2.**=exhaust valve and **3.**=simulation window.

RESULTS

Smoke visualization of air distribution in full occupancy summer cases is shown in Fig.2. Thermal plumes did not have a significant effect on the performance of a wall-grille: the momentum flux of a wall-grille was strong enough to attain the other side of room (even it worked with smaller air flow rate of 45 l/s). Also, the supply 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 plume moving direction in the perimeter zone (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.

The velocity measurement results from different cases are shown in Figs. 3-6. In all conditions with a wall-grille, there exists high velocities (over 0.3 m/s) over the occupied zone. 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 units. With a ceiling diffuser, air velocities were reasonable low in all cases (0.19-0.23 m/s). With a perforated duct diffuser, there existed locally high velocities (0.2-0.3 m/s) and 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.

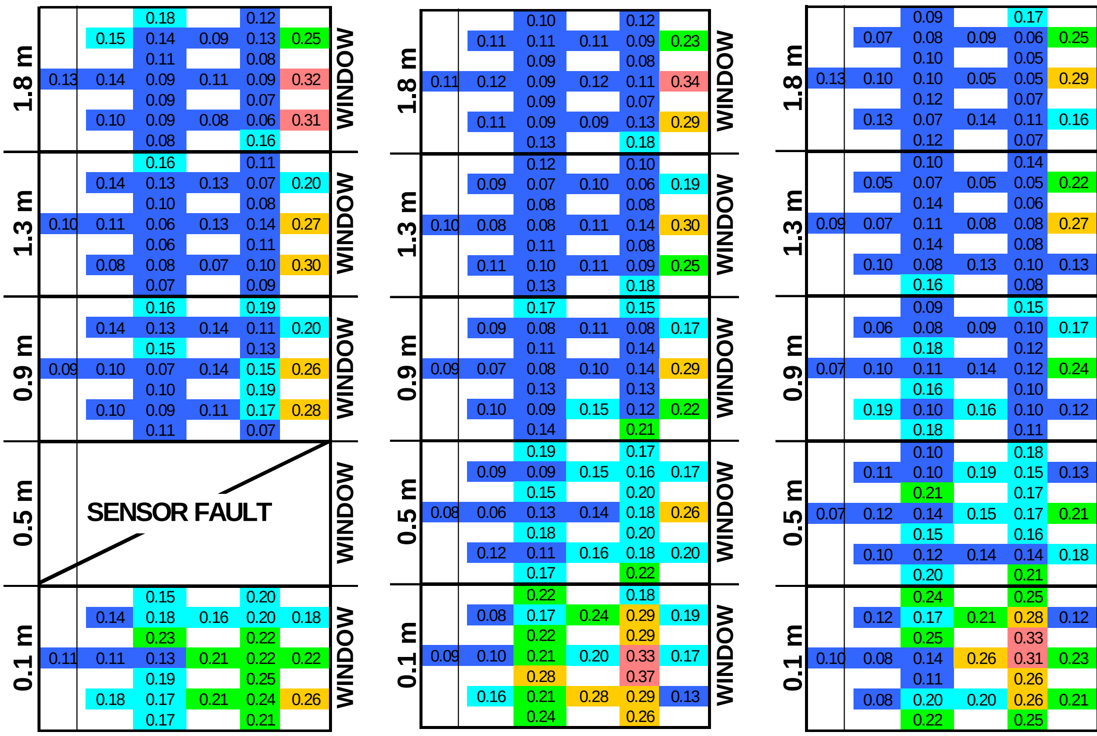

Figure 3. Velocity distribution of **a wall-grille** at 0.1m - 1.8m heights from floor. Cases: summer full occupancy (right), summer half occupancy (middle) and winter half occupancy (right). Colour codes: level 0-0.14m/s blue, 0.15-0.20m/s turquoise, 0.21-0.25m/s green, 0.26-0.30 yellow and over 0.31m/s red.

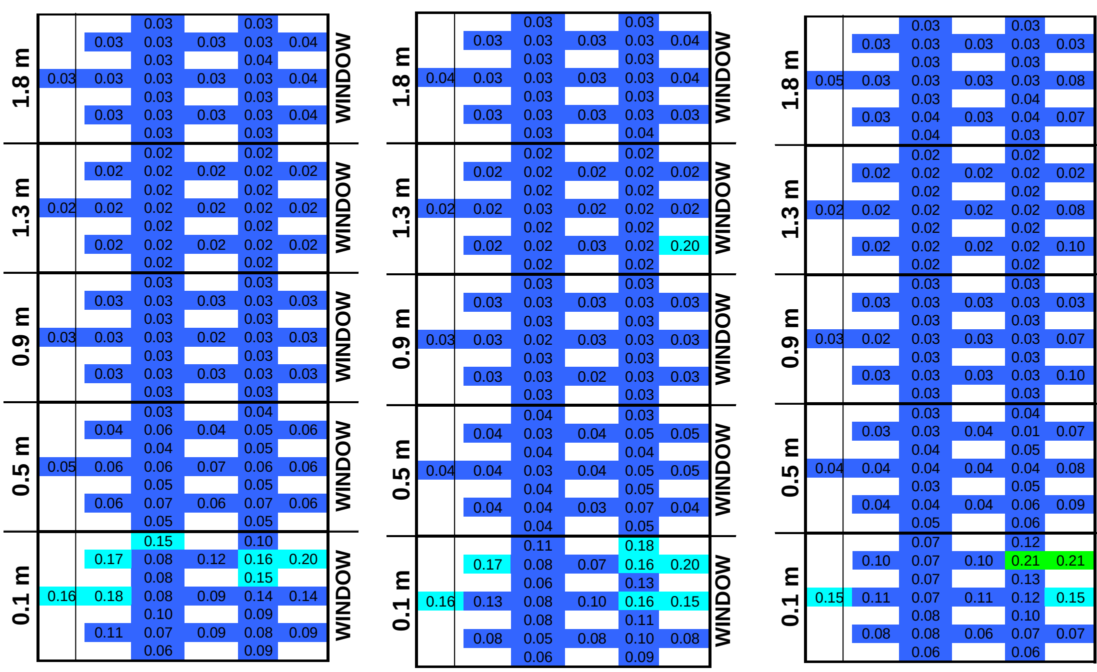

Figure 4. Velocity distribution of **a displacement ventilation concept** at 0.1m - 1.8m heights from floor. Cases: summer full occupancy (right), summer half occupancy (middle) and winter half occupancy (right). Colour codes: level 0-0.14m/s blue, 0.15-0.20m/s turquoise, 0.21-0.25m/s green, 0.26-0.30 yellow and over 0.31m/s red.

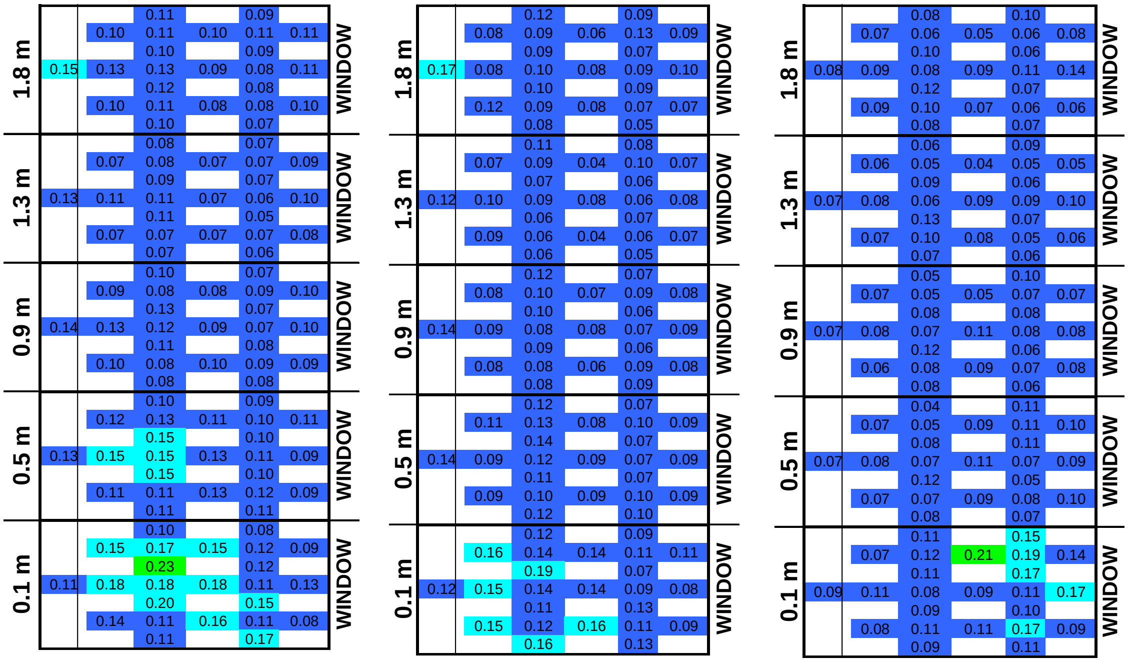

Figure 5. Velocity distribution of **a ceiling diffuser** at 0.1m - 1.8m heights from floor. Cases: summer full occupancy (right), summer half occupancy (middle) and winter half occupancy (right). Colour codes: level 0-0.14m/s blue, 0.15-0.20m/s turquoise, 0.21-0.25m/s green, 0.26-0.30 yellow and over 0.31m/s red.

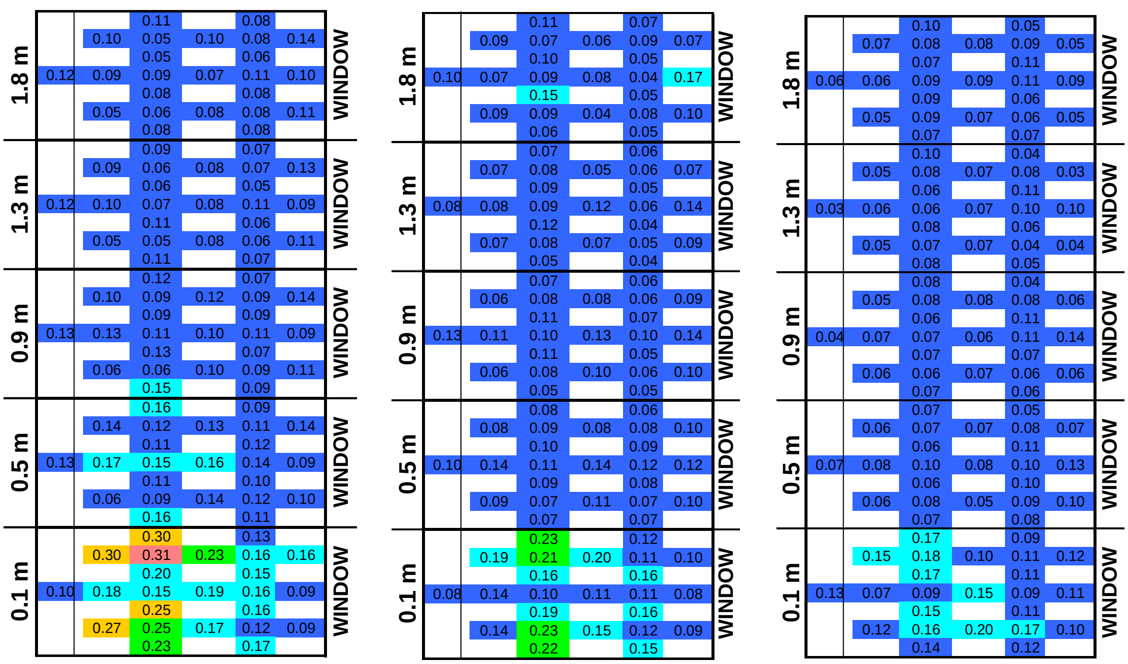

Figure 6. Velocity distribution of **a perforated duct** diffuser at 0.1m - 1.8m heights from floor. Cases: summer full occupancy (right), summer half occupancy (middle) and winter half occupancy (right). Colour codes: level 0-0.14m/s blue, 0.15-0.20m/s turquoise, 0.21-0.25m/s green, 0.26-0.30 yellow and over 0.31m/s red

The measured vertical temperature distribution in the middle of the room is shown in Fig.7. With mixing ventilation concepts (a wall-grille, a ceiling diffuser and a perforated duct diffuser), room air was fully mixed. With a displacement concept, there exists temperature gradient in all cases. The vertical temperature stratification in the occupied zone of the displacement ventilation case was still acceptable (< 3 K/m).

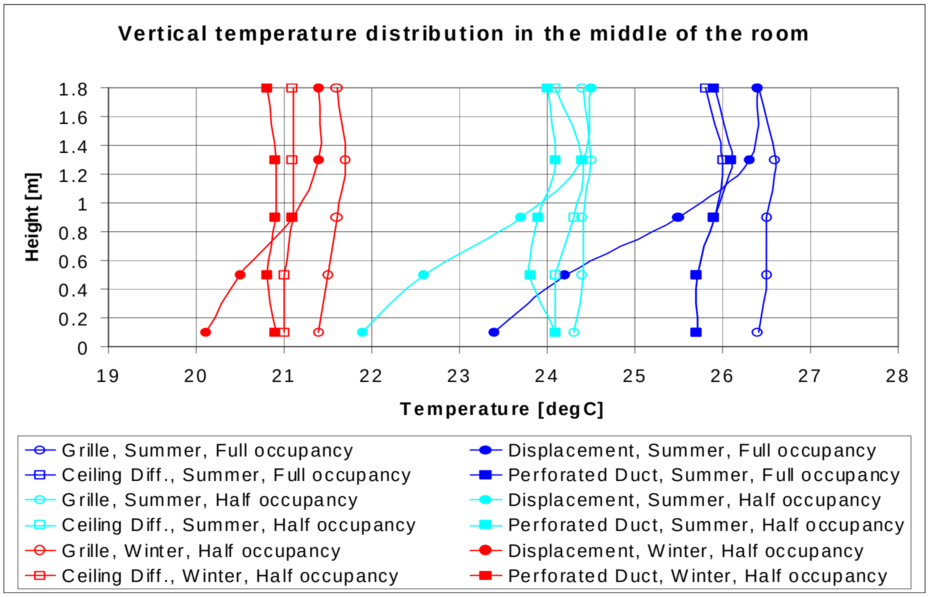

Figure 7. Vertical temperature distribution in the measurement cases.

DISCUSSION

In the studied classroom, there existed to some extent higher velocities close to the supply units when displacement ventilation concept was used. Still, the average conditions of thermal comfort in the occupied zone were the best. In real projects, the location of the supply units should be carefully analyzed to prevent near-zone draft. The space constrain should be project-based analyzed when the location for the displacement units are selected. Displacement ventilation was also the least sensitive of all studied supply concepts for different load conditions. Air distribution pattern was not changed in different load conditions.

Air distribution with corridor wall-grille gave high velocities in all load conditions. In winter conditions, air velocities even rised close to the window. It should be noted that the performance could be optimized in one selected load conditions. In principle, the throw length could be optimized for winter conditions resulting to lower velocities close to the window workplaces e.g. by selecting a larger wall-grille. This increases draft risk in summer conditions when thermal plumes affect on the performance causing early jet detachment from the ceiling. Further, the detachment can lead indoor air quality problems when the supply jet reaches only a minor part of the occupied area.

The supply air jet from the ceiling diffuser tended to be conveyed by thermal plumes from the heat loads during summer times. In winter when there was no effect of a window plume, air distribution was more uniform. The function of the ceiling diffuser concept is quite appropriate in varied load conditions. Together with displacement ventilation, the ceiling diffuser concept is a recommended solution for classrooms.

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

In mixing ventilation concepts, load conditions have a significant effect on the air distribution. When the air distribution strategy is designed the system performance should be analyzed in different conditions. In practice, the problem is that in the design phase without using CFD- simulation or laboratory mock-ups it is not possible to analyze the interaction of convection flows and jets. It is recommended to use CFD or mock-up analysis to guarantee the performance of air distribution in varied load conditions.

CONCLUSIONS

The quality of the indoor climate and thermal conditions in schools have been found to be poor in a number of surveys. To analyze 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.

ACKNOWLEDGEMENT

The study is supported by Technology Agency of Finland (TEKES). The authors wish to thank to Mr. Harri Itkonen for his comments.

REFERENCES

1. Daisey, J.M, Angell , W, J, Apte M.G. 2003. Indoor air qaulity, ventilation and health symptoms: an analysis of existing information. Indoor Air. 13 p. 53-64.
2. Mendell, M.J and Heath, G.A. 2005. Do indoor pollutants and thermal conditions in school influence student performance ? A critica review of the literature. Indoor Air. 15. p. 27-52.
3. Wargocki, P, Wyon, D. P, Matysiak, B and Irgens S. 2005. The effects of classroom air temperature and outdoor air supply rate on the performance of school work by children. Indoor Air Beijing, the 10th international conference on indoor air and climate, vol. I (1) p. 368-372.
4. ISO 7730. 2005. Ergonomics of the thermal environment- Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria.
5. Kurnitski, J. 2007. Indoor climate and ventilation in Finnish schools. Air distribution and temperature control in classroom. Rehva Journal. Vol. 44 number 2. pp. 15-22
6. Kosonen R, Melikov A, Yordonova B and Bozkhov L. Impact of heat load distribution and strength on airflow pattern in rooms with exposed chilled beams . RoomVent 2007 10th International Conference on Air Distribution in Rooms. Proceedings of Roomvent 2007 Helsinki 13-15 June 2007.
7. DIN 4715-1. 1995 Chilled surfaces for rooms – Part 1: Measuring of the performance with free flow – Test rules (English version). Deutsche Institut für Normung.