High performance schools: displacement ventilation an improvement?

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ABSTRACT

Ventilation in schools is very important as it has a direct relation to health and performance of pupils. The status quo of school ventilation in the Netherlands is presented: lots of problems and insufficient situations were found. Different aspects of the problems were studied to find new solutions.

A new Integral Design approach was developed to design adequate solutions for ventilation of school buildings. The design procedure and a first design result are described: a displacement ventilation system for indoor climate control of schools.

The design is implemented in an existing school and measurements were done in this school. In an existing school building a new displacement ventilation system was installed in a classroom. Afterwards during several weeks all relevant parameters were measured to calculate the PMV values. In the same period users of this classroom had to fill in a questionnaire in which they rated temperature, stability of temperature and air speed.

The measurements and calculations provide an insight in the effects of displacement ventilation on the climate itself and the individual perception of the thermal comfort. Bench marking of specific parameters concerning thermal comfort gives a clear picture of the performance of the concept.

Displacement ventilation is good solution for classroom ventilation.

KEYWORDS

Schools, Displacement ventilation, Thermal comfort, Indoor Air Quality.

INTRODUCTION

Most ventilation systems in Dutch primary schools do not provide acceptable indoor air quality (IAQ) nor fulfil thermal comfort requirements (Habets et al 2006, De Gids et al 2007, Joosten 2004, van Bruchem 2005). Most schools have natural- or exhaust only ventilation systems. These systems often have draught problems resulting in human intervention (especially during winter, e.g. closing windows). Ventilating fresh air improves IAQ, learning performance and reduces sick leave (Myhrvold et al 1996, Wargocki et al 2005). Because of high occupancy, school classes need a large amount of fresh air supplied in a comfortable and cost effective way guaranteed throughout the year. A promising (cost) effective ventilation solution is displacement ventilation (DV) because of its high ventilation-efficiency (Skistad et al 2004).

Dutch primary schools need a ventilation system which is able to supply and guarantee a large amount of air in a comfortable and efficient way throughout the year. Earlier design research conducted (van Bruchem 2005) concluded that a displacement ventilation system could be able of supplying a large amount of air with a low velocity while giving no draught problems. Although this system seems to have a high potential as ventilation system in primary schools, more research is needed to obtain a better understanding of the critical factors of applying such system in a typical Dutch (primary) school environment. According to Skistad et al (2004) a displacement ventilation (DV) is in first place meant to obtain a good air quality into the occupied zone. DV is suitable in rooms where the main heat sources are also the contaminant sources (like pupils); a classroom is a good example. A displacement ventilated classroom needs less fresh air (when compared to often applied mixing ventilation) to gain the same indoor air quality. This involves an energy reduction. Mattsson (1999) conducted research on the performance of DV systems in classrooms under laboratory conditions. It seems that for example people movement demolishes the displacement effect, but the displacement flow pattern was re-established fairly quickly after ceasing the activity. In all test cases of his study he found that the air quality in the breathing zone of seated occupants remained significantly better than that at perfect mixing conditions.

METHODOLOGY: FIELD TEST WITH DISPLACEMENT VENTILATION

The objective of this research is to obtain a good indoor air quality in primary schools by developing, constructing and validating a “standard” displacement ventilation solution that can be generally applied in these schools. In spite of the fact that a laboratory environment is commonly used for measurements to validate ventilation systems (because of the controlled steady state conditions that can be achieved) it is important to prove the efficiency of the ventilation system in an existing classroom environment. Several depending and dynamic physical variables need to be examined and monitored to obtain a reliable judgment of the DV system. With the help of measurements the following aspects of a DV system were formed:

- The current status of the IAQ and thermal comfort (reference conditions without a ventilation system) and perception of the users with respect to IAQ and thermal comfort (with a survey);
- The considered reduction of the CO2 concentration as a result of a DV system.

For the measurements a tripod was used in the middle of the room on which were placed the different sensors. To get a more detailed insight in the IAQ in the classroom for the pupils a person simulator (PS) is used to validate (better) air quality in the breathing zone. The air quality near the body of a human in a displacement ventilated room is verifiable better due to thermal buoyancy which stimulates fresh air supply from beneath. The buoyancy forces near. Mattsson [8] also used a person simulator to measure the displacement effect near the body in his research. The dimensions of the PS are determined by the furniture of the classroom and the average body surface of the pupils. Thermo graphical pictures were made to compare the surface temperature of the PS with a real human. The PS is used to mount on resistance thermometers and CO2 sensors, see Fig. 1.

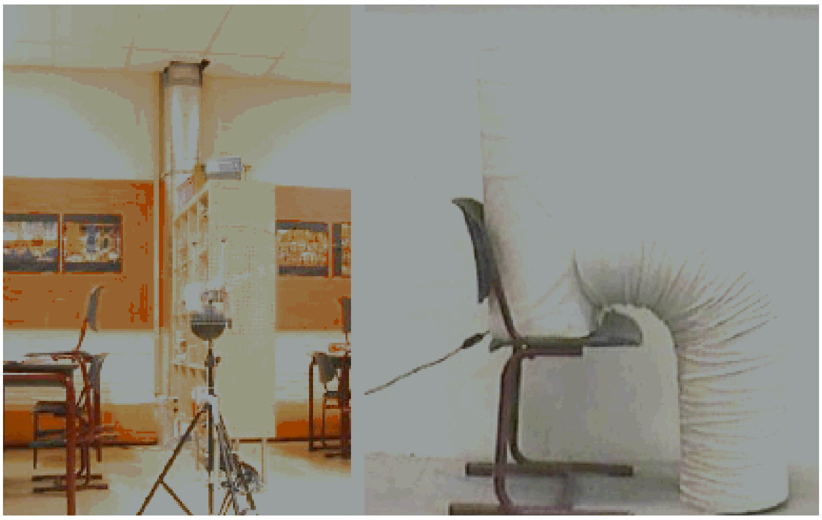

Figure 1. Tripod and Personal Simulator used for the measurements [9]

An enquiry was executed two times to obtain an indication of the IAQ and thermal comfort perception of the pupils, one before and one after the ventilation system was turned on. The interval between each enquiry was one month. The pupils were asked to judge the indoor climate based on the last two weeks according to a 7-point scale. Subsequently, the perception of the pupils is weighted (according to the 7-point scale). The scores from the 7-point scale are weighted from negative -3 and +3 with a minimum appreciation to neutral 0 with a maximum appreciation.

EXPERIMENTAL SET-UP

The measurements are carried out in a full-scale classroom (in use) approximately the size of a typical classroom in the Netherlands (see picture 1). The floor area of the classroom is 7,72 x 7,3= 56,4m2 with a ceiling height of 3,13 m and a total space volume of 176 m3.

Some steady state measurements are performed in an empty classroom and others are performed in an occupied classroom to obtain buoyancy sources in accordance with normal classroom activities. The classroom is used by 26 pupils from group 7/8 (age 10-12 years) in standard school conditions. The façade has eight windows of which four can be opened by the teacher. The opposite wall contains six windows (four bordering the outdoor climate) of which none can be opened. The classroom has two doors, one to the classroom nearby (isn't used) and one door to the corridor. The indoor blinds system (four sections) can be lowered by the teacher to avoid direct sun radiation in the morning.

Three existing radiators with a total capacity of 23500 W (at 90/70ºC) are provided with manually controlled radiator valves to adjust the room temperature. Fresh air could be supplied into the classroom by the windows in the façade.

New ventilation system

An air handling unit is mounted on the outer wall of to the classroom, see figure 1. The air handling unit is provided with a plate heat exchange system to recover sensible heat from the exhaust air. The air is transported by a duct system which is mounted above the lowered ceiling in the classroom. An additional electric heater is placed which is connected to a temperature sensor nearby the supply diffusers, to obtain a minimal supply temperature of 18ºC in winter (only for fine tuning of the air supply temperature). The ventilation flow can be adjusted by a control panel which communicates with electronically commutated ventilators in the air handling unit and is fine-tuned with control valves. The air flow can be measured by prefabricated measuring instruments in the supply and the extract duct system. The air supply temperature is regulated by an electrical heating battery which is connected with a temperature sensor in the supply duct system. Two semicircular textile air diffusers (so called air socks) for displacement ventilation are mounted on the wall, at floor level of the backside of the classroom. The main supply duct is vertically placed in the middle of the wall at the backend of the room. An air distribution box is placed at the end of the duct at floor level to divide the air flow over the textile air diffusers. The textile air diffusers have a length of 1,7 meters with a zipper at 0,5 meter to shorten the length (to 1,2 meter) and increase the supply velocity. Next, two exhaust grilles are mounted in the lowered ceiling on the opposite side of the classroom (see Fig. 2).

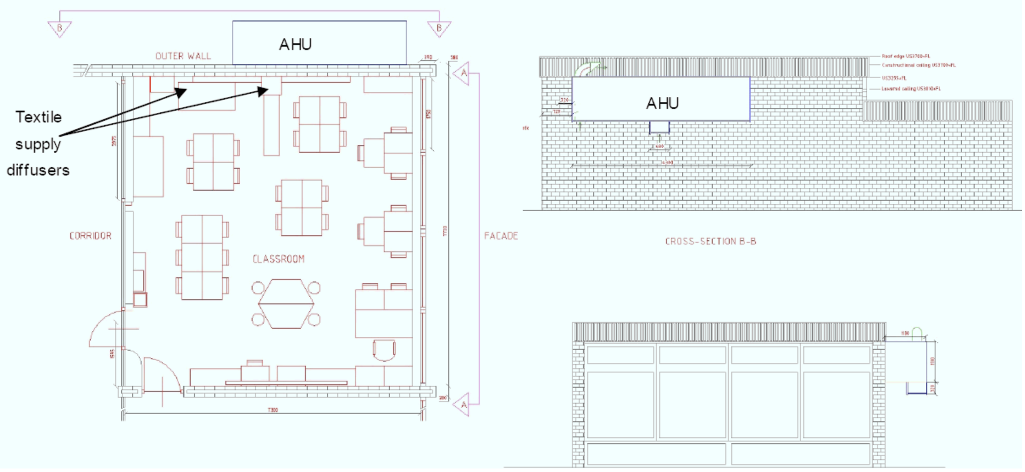

Figure 2. Experimental set-up [9]

The ventilation system of the classroom consists of:

- 1 Air handling Unit (AHU): nom. capacity 1000 m3/h at 300 Pa with electronically commutated ventilators with free set point;
- 1 electrical heating battery, capacity 1500W;
- Duct system Ø 250 mm, maximum velocity 5,5 m/s ;
- 2 horizontal displacement diffusers made of fire retardant textile;

Reference conditions of the classroom

The measurements took place during one week from 3rd till 7th of March 2008. The mentioned values are measured within the school lessons. Throughout the week the average indoor room temperature is reasonably constant, approximately 20ºC. Also the relative humidity is reasonably well with an average value between 40-50%. The indoor air quality, which is measured by the CO2 concentration, exceeds the limit of 1200 ppm by 55% and the desired value of 1000 ppm by 86%!. This is quite unacceptable but unfortunately occurs often within Dutch primary schools.

RESULTS

After installing the new system ventilation measurements took place on a normal school day with morning and a afternoon session. The occupation was constant with 23 persons and when the ventilation system turned on the air flow per person was 22 m3/h (6,1 l/s). Before the start of the school day (first period) the ventilation system was turned off. After one hour the CO2 concentration was between 1700 and 1900 ppm just before the ventilation system was turned on. Within the first three minutes the CO2 concentration at the PS sensor was decreasing. After twelve minutes the CO2 concentration at the wall- and the tripod sensor were decreasing. It is plausible that the displacement effect at the PS causes the extract sensor to decrease earlier than the wall- and tripod sensors (after six minutes). The second period started after the morning break at 10:45 when the system was turned off again. After three quarter of an hour the CO2 concentration was build up again to a value between 1500-1750 ppm. Subsequently the ventilation system was turned on and the sensor of the PS again decreased within the first three minutes. The other sensors follow after twelve minutes except for the extract sensor with an obvious decrease after six minutes. Just before lunch break the CO2 concentration was around 1000 ppm at the PS sensor and between 1200-1300 ppm at the other sensors (and declining), see Fig. 4.

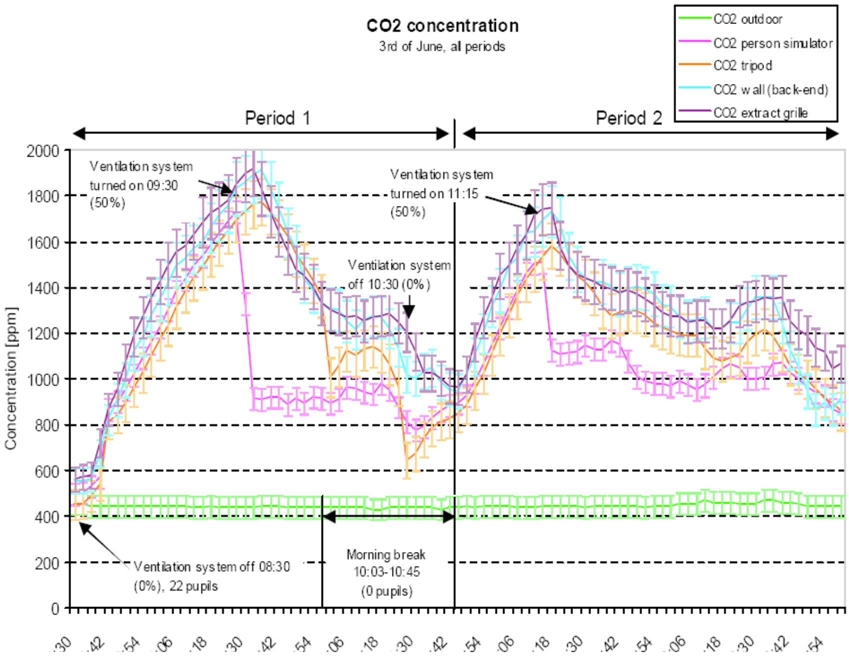

Figure 3. CO2 concentration curves of the efficiency measurement July 3rd

Theoretically, the DV system needs an air flow rate of 6.75 l/s per pupil to obtain an average CO2 concentration of 1000 ppm (at 430 ppm outdoor). In our experiment it was shown that the mean CO2 concentration was almost 1000 ppm on the first and second day, achieved by a ventilation rate of 5.4 and 5.6 l/s per pupil. The measured ventilation per pupil is approximately 17% lower than the calculated values. This might be explained by the fixed ventilation efficiency of 1.3.

Table 1. Performance of the DV-system derived from CO2 concentrations

Day	Ventilation rate per person [l/s.pp]	CO2 outdoor (error) [ppm]	CO2 theoretical [ppm] ventilation-efficiency 1.3	Mean CO2 measured (error) [ppm]	CO2 Difference [%]
1: 30-05-08	5.4	437 (±48)	1146	995 (±92)	15
2: 29-05-08	5.6	431 (±48)	1112	999 (±88)	11
3: 24-04-08	7.0	420 (±47)	967	908 (±97)	6
4: 28-05-08	8.9	418 (±47)	851	660 (±77)	29
5: 27-05-08	9.7	422 (±47)	821	802 (±79)	3

Vertical temperature gradient and draught

Figure 4a shows that the maximum air velocity is at 2 cm above floor level and the air velocity reduces to 0,11 m/s at 10 cm. Moreover, the air velocity is stabilized at 5 cm (0.14-0.15 m/s) for all distances. Since this is ankles' height, it is the critical height for draught problems. For the observed configurations the pupils can be seated at 0.5 meter from the textile air diffuser without draught problems.

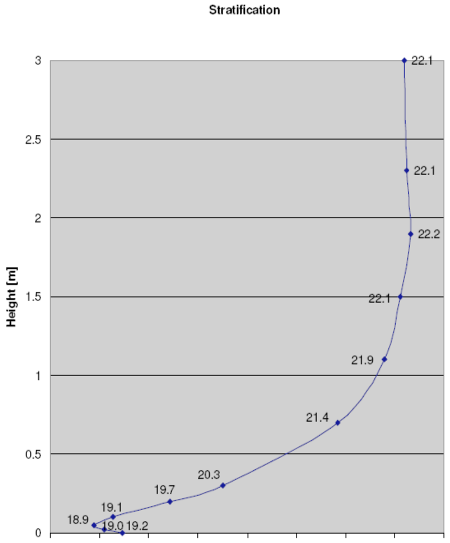

Figure 4a (above) air velocity at different heights and distances

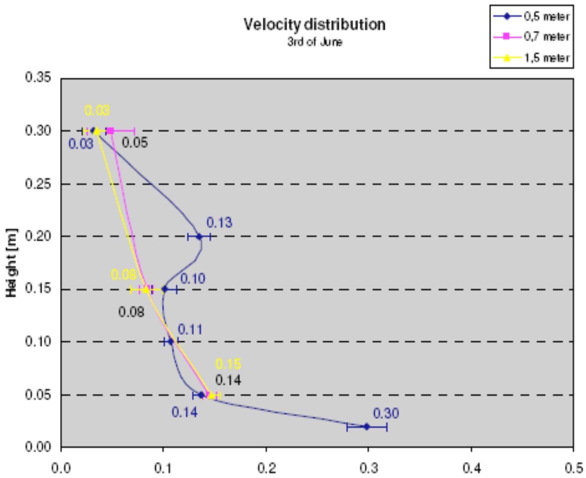

Figure 4b (right) vertical temperature gradient, temperature gradient between 0.1 and 1.1 meter

The draught rating values remained below 20% (mean 14%) and the turbulence intensity values remained below 50% (mean of 16%) according to CR 1752 (1999). The mean air supply temperature was around 19 ºC. Figure 4b shows the maximum vertical temperature gradient (between ankle and head) of all measurements collected and remains just below 3 K/m.

Results questionnaires

The results of the questionnaires according to the ASHRAE 7 points scale were transformed to a scale of 0-10. The average score between 0-10 is calculated by dividing the actual score to the maximum score. Figure 5 shows the perception of the pupils with respect to the IAQ and thermal comfort aspects. The scoreboard is scaled with 10 as an optimal situation. Two experiments are shown, the ventilation system turned off and the system turned on. On almost all aspects the ventilation system performs better working than not working. It's remarkable that pupils feel the same at the "Satisfying IAQ", "Comfort classroom" and the "Odors" aspect. The "Overall feeling" is even better when the ventilation system stays off. The pupils experience more "annoyance of noise" which is probably produced by the ventilation system. In spite of the measurements indicating more significant values, the pupils' opinion of the ventilation system is slightly better than when the ventilation system is turned off and the windows are opened sometimes.

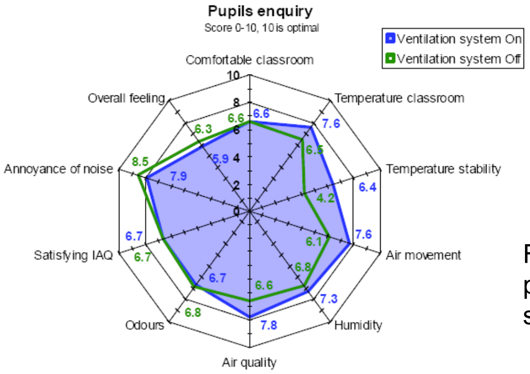

Figure 5. Average opinions of pupils for several aspects on a scale from 0 to 10

CONCLUSIONS

High performance schools are meant to give their pupils the best surrounding for their learning situation. Adequate thermal comfort and good performance are therefore essential. The current proposed DV system could make from ordinary schools, high performance schools, as a major improvement could be made for the thermal comfort and IAQ conditions.

The measurements were performed during normal working houres in a typical Dutch school buildings' classroom. As expected, the reference conditions of the examined school building were not adequate: the average CO2 concentration, the indicator for IAQ, is high (above 2000 ppm).

The measurements give an indication of the performance of the new installed DV system. The DV system is effective to improve the IAQ to an acceptable level. The DV system provides average CO2 concentration below 1000 ppm with a lower ventilation rate compared to mixed ventilation systems. This has been achieved without exceeding the threshold limits of vertical temperature gradient and draught. The results of the questionnaires did not significant differ from the measured IAQ aspects.

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