Indoor Climate and Ventilation in Finnish Schools Air Distribution and Temperature Control in Classrooms

Abstract
Finland is a country without a debate on natural ventilation. In such a cold climate, it has been easy to learn the lessons regarding inadequate ventilation and the many complaints from older schools with mechanical exhaust or passive stack ventilation.

Finnish code value for classroom ventilation is 6 L/s per person or 3 L/s per m^2 which is provided by mechanical supply and exhaust ventilation systems equipped with effective filters and heat recovery.

Today Finland discusses how to renovate old school buildings from sixties and seventies so that today's standard with 6 L/s per person ventilation will be achieved. Advanced demand controlled systems with supply air temperature compensation are used in many schools.

The latest task performance results indicate the need for even higher ventilation rates than used today. Ventilation rates of about 10 L/s per person will lead to large airflows of about 5 L/s per floor m^2. In such cases an effective air distribution scheme will be crucial in order to avoid drafts.

In this paper air distribution solutions aiming to lower air velocities and good temperature control are studied by measurements in 6 schools and temperature simulations.

Air velocity measurements showed good performance of duct and ceiling diffusers which provided maximum velocities less than 0.2 m/s and can be highly recommended for classrooms.

The wall diffusers were clearly not suitable for classrooms due to high velocities up to 0.43 m/s. Displacement ventilation diffusers were very sensitive to supply air temperature, as with the temperature difference of 3°C velocities up to 0.28 m/s were measured.

Room temperature measurement results showed a typical problem with temperature control as at the end of the heating season the temperatures up to 25°C were measured.

The parametric simulations showed that high supply air flow rates up to 10 L/s per person and cool supply air down to 14-15°C were needed for room temperature control.

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Dr. Kurnitski, born in 1970, is REHVA and SCANVAC awarded scientist leading the research group at Helsinki University of Technology, Finland. This multi-disciplinary research group has successfully contri-buted to many EU-projects in the area of indoor environment and energy efficiency of buildings. He has actively participated in the working groups of European Standardisation Organisation (CEN) to develop European standards for implementation of Energy Performance in Buildings Directive, as regards indoor climate and ventilation. His list of publications includes 130 items of which 20 articles in international journals with strict referee practice. He has contributed to the development of Finnish Classification of Indoor Climate that is most advanced guideline for good indoor environment in developed world, and widely referred. Finnish Healthy Construction Criteria was developed under his leadership. This document integrates the Classification of Indoor Climate into the construction process and is further specification for the construction utilizing performance based approach.

1. Introduction

Many studies have shown that poor indoor environmental quality (IEQ) in office buildings can reduce the performance of office work by adults[1,2]. While it is well documented that IEQ in schools is both inadequate and frequently much worse than in office buildings[3], there is little direct evidence that classroom performance is being negatively affected[4]. Experimental interventions[5,6] show that increasing the outdoor air supply rate and reducing moderately elevated classroom temperatures significantly improved the classroom performance of many tasks, mainly in terms of how quickly each pupil worked (speed). In these experiments the room temperature was reduced from 25°C to 20°C and the outdoor air supply rate was increased from 5.2 to 9.6 L/s per person. Thus the results suggest that higher ventilation rates up to 10 L/s per person as well as more strict temperature control than commonly used can be recommended for classrooms. This means new challenges in the design of classroom ventilation and temperature control. High airflow rates and low supply air temperatures, which are needed for temperature control, may easily cause draft. This may be avoided by careful selection of air distribution solutions and terminal devices.

In this study, air distribution solutions for classrooms aiming to lower air velocities and good room temperature control are studied by measurements in classrooms and temperature simulations. Performance of wall, ceiling, duct and displacement diffusers is compared at ventilation rates up to 340 L/s per classroom and supply air temperatures up to 6°C lower than room temperature. Based on the results, design guidelines of air distribution and temperature control solutions leading to healthy and productive indoor environment in classrooms can be given.

2. Methods

Air velocity, room temperature and CO_2 measurements were done in 6 schools. All schools were either relatively new buildings or renovated buildings, all having modern mechanical supply and exhaust ventilation systems with ventilation rates, corresponding at least to Finnish minimum code requirements for ventilation of new buildings.

School D had air distribution by ceiling diffusers (two diffusers per classroom) and school B by wall diffusers (two diffusers per classroom), which represents a low cost solution most commonly used. In three schools (A, C, E) duct diffusers (two ducts per classroom) and in school F displacement ventilation diffusers were used, ***Figure 1***.(see next page)

In schools from A to D, temperature and CO_2 concentrations were measured during a one week period in May 2006 from three classrooms in each school. Air velocity measurements were done in one classroom. In E velocity was measured in two classrooms and supply air temperature was set by 4 to 6°C below the room temperature. In F data from previous measurements[7] was used to compare the performance of displacement ventilation to mixing ventilation. Air velocity measurement points were selected with smoke tests, so that the highest velocities could be measured. The measurement points are shown in ***Figure 2***.(see next page)

Both constant air volume (CAV) and demand controlled (DCV) ventilation systems with constant or controlled supply air temperature were used in schools. Differences between DCV and CAV systems and supply air temperature control options were studied with temperature and ventilation simulations for typical classrooms with a varying heat load.

3. Results

3.1. Measurement results in the schools

Supply air flow rates measured from terminal devices and typical occupancy in the classrooms is shown in ***Table 1***. E was a new school having almost doubled supply airflow rate (design value of 12 l/s per person, 340 l/s in total) and also other target values of the highest indoor climate class. Schools A and B had CO_2- and CO_2&temperature controlled ventilation with 3 and 2 airflow steps respectively. In other schools constant air volume systems were used. A to D had a constant supply air temperature and in E and F supply air temperature was controlled according to exhaust air temperature.

Table 1. Measured supply air flow rates and typical occupancy in the classrooms

School	Occupancy, pers	Supply air flow rate, L/s per pers.	Supply air flow rate, L/s	Design supply air flow rate, L/s
A	20	7	138	210/150/90
B	27	7	186	210/30
C	22	6	136	175
D	20-25	6.8-8.2	168	170
E			348	340
F			180	180

Outdoor temperature during the measurement week was typical spring weather, between 9...12°C. This represents the end of heating season and the results are compared to heating season target values. Room temperature and CO_2 results from classrooms where air velocity measurements were done are shown in ***Figure 3***. Results are given only from the

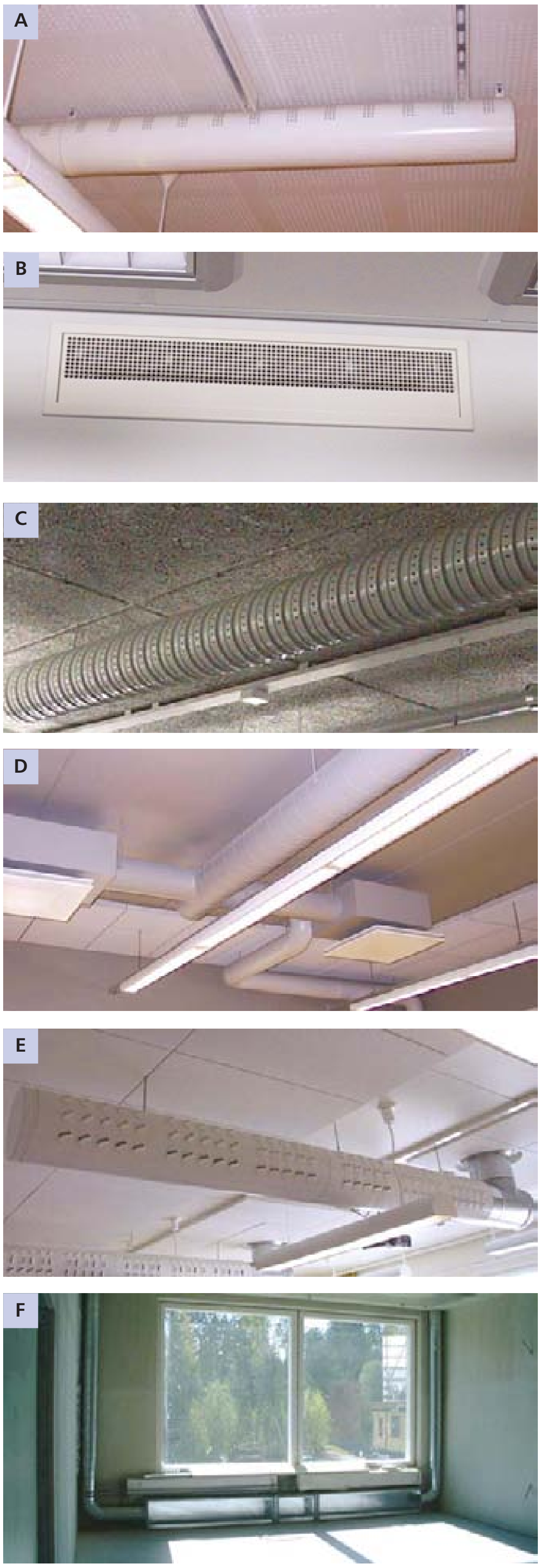

Figure 1. Air distribution in schools. A duct diffusers, B wall diffusers, C duct diffusers, D ceiling diffusers, E duct diffusers and F displacement diffusers

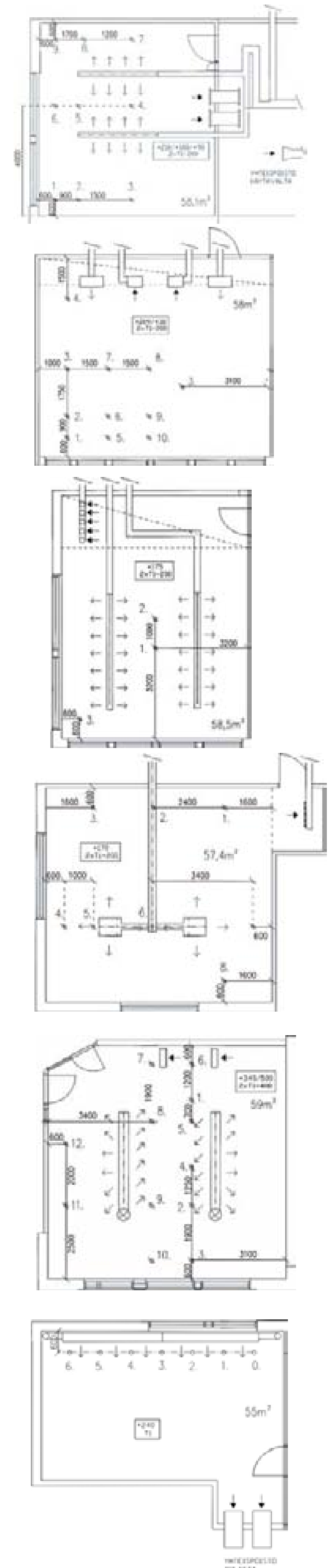

Figure 2. Air velocity measurement points in the classrooms

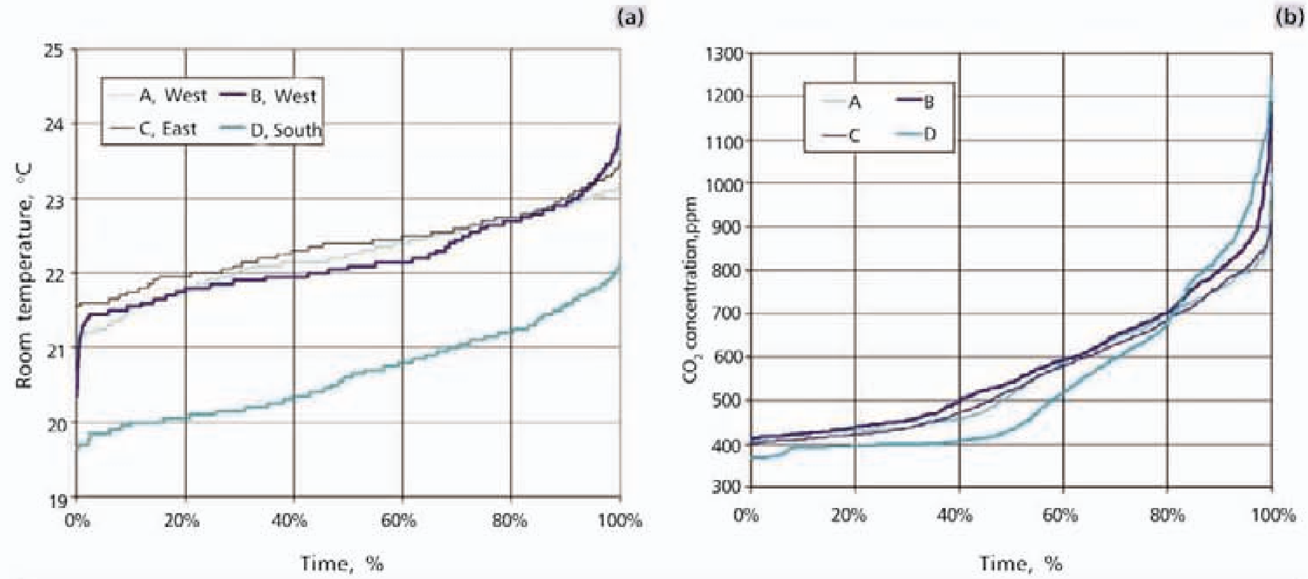

Figure 3. Duration curves of room temperature, (a) and CO_2, (b); data from 8.00 to 15.00 on week-days

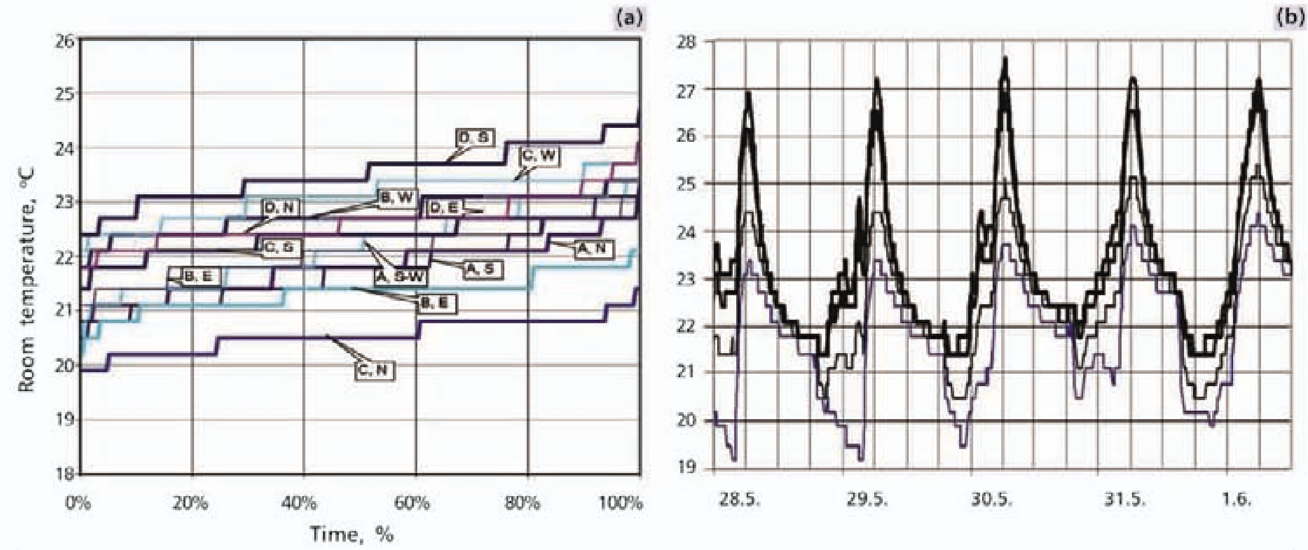

Figure 4. Duration curves of temperatures in other classrooms in A to D from 8.00 to 15.00 on week-days, (a) and temperatures from E during 28.5-1.6.2003, (b)

Table 2. **Maximum detected air velocity values from the occupied zone at three measurement heights.** *Locations of the all measurement points are shown in Figure 2.*

	Meas. Point	Air Velocity, m/s Measurement height			Operative temperature,	Supply air temperature,	DT, room - supply air temperature,
		0.1 m	1.10 m	1.80 m	°C	°C	
A, duct diffusers, 138 L/s	2	0,25	0	0,13	24,7	20,4	4,3
	6	0,03	0,13	0,2	24,9	20,4	4,5
	9	0,18	0,29	0,08	24,6	20,4	4,2
B, wall diffusers, 186 L/s	1	0,18	0,43	0,15	22,6	20,4	2,2
	2	0,3	0,09	0,06	22,7	20,4	2,3
C, duct diffusers, 136 L/s	1	0,1	0,07	0,16	22,6	19,8	2,9
D, ceiling diffusers, 168 L/s	4	0,03	0,05	0,14	21	19,4	1,6
	7	0,11	0,06	0,06	20,7	19,4	1,3
	8	0,08	0,09	0,07	20,7	19,4	1,3
E, duct diffusers 348 l/s	3	0,17	0,09	0,09	21,7	17,4	4,4
	7	0,7	0,011	0,013	21,4	17,3	4,1
E, duct diffusers 348 l/s	7	0,1	0,14	0,19	21,9	16,2	5,7
F, displacement diffusers 180 l/s	4	0,28	-	-	-	-	-

school time period which is from 8.00 to 15.00 on week-days. Temperatures measured from other classrooms in schools A to D (measured with loggers with a lower resolution compared to Figure 3) and previously measured temperatures from G are shown in *Figure 4*.

Air velocity measurements were done from the locations selected with the smoke test as shown in *Figure 2*. Maximum velocities from the occupied zone at three measured heights are reported in *Table 2*. In A to D supply air temperature was not adjusted, but just measured.

In E and F the effect of supply air temperature on draft was studied by changing the temperature of supply air and repeating the velocity measurements. In F with displacement diffusers the results were very sensitive to the temperature difference. Air velocities at 0.1 m height, 0.6 m from diffusers, were 0.14…0.18 m/s when supply air temperature was equal to room temperature. Measurements with the temperature difference of 3 °C gave higher velocities, as shown in ***Table 2.***

3.2 Room temperature simulations

Temperature control and ventilation rate options were simulated with IDA-ICE software for CAV and DCV systems without mechanical cooling in order to find good solutions for classroom ventilation and temperature control. The time period was chosen according to the typical use of schools: heating season from Jan 2 to May 14 and Oct 1 to Dec 23, and summer season from May 15 to May 31 and Aug 15 to Sept 30. Two classrooms were simulated as this configuration gave the same results as the configuration with six classrooms, ***Figure 5.*** A classroom with 30 students faced south and another with 20 students north. The occupancy profile used and the control curve of supply air temperature determined in the simulations are shown in ***Figure 6.*** For the south classroom, solar protection glasses were used.

Two ventilation rates, 6 L/s per person, 180 L/s per classroom in total, and 10 L/s per person, 300 L/s per classroom in total, were simulated. For both rates

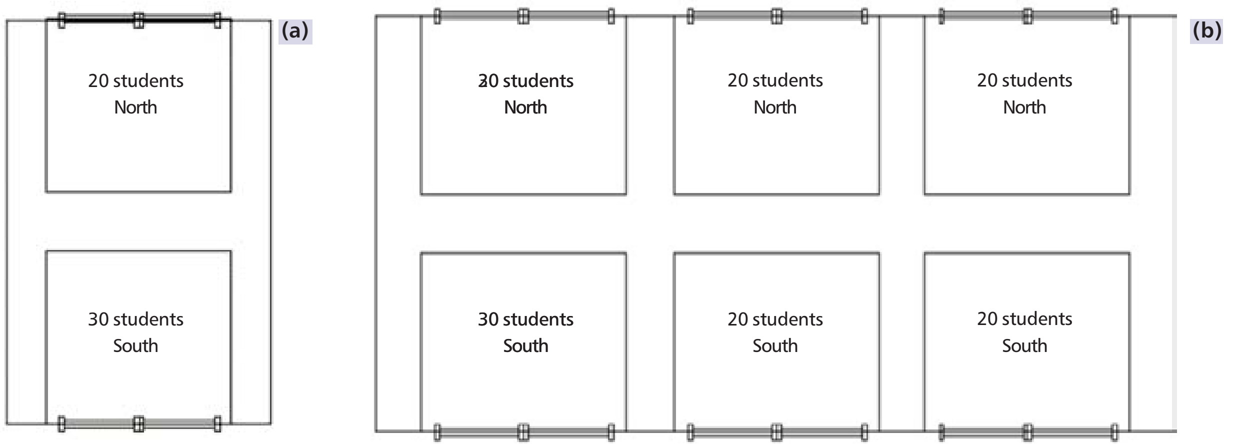

Figure 5. *The configuration of 2-classrooms used in the simulations, (a) The configuration of 6-classrooms used for the testing of 2-classroom configuration, (b)*

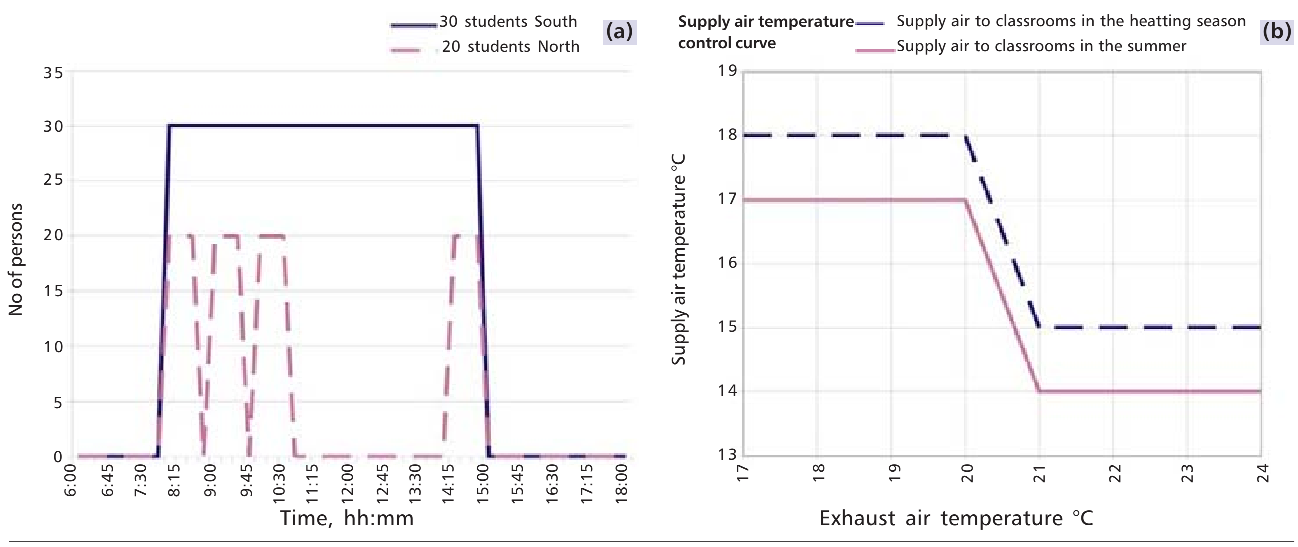

Figure 6. *The occupancy profile of students, (a) and determined supply air temperature control curve, (b) (supply air temperature values can only be achieved if outdoor temperature is lower than supply air temperature, as there is no mechanical cooling in the system)*

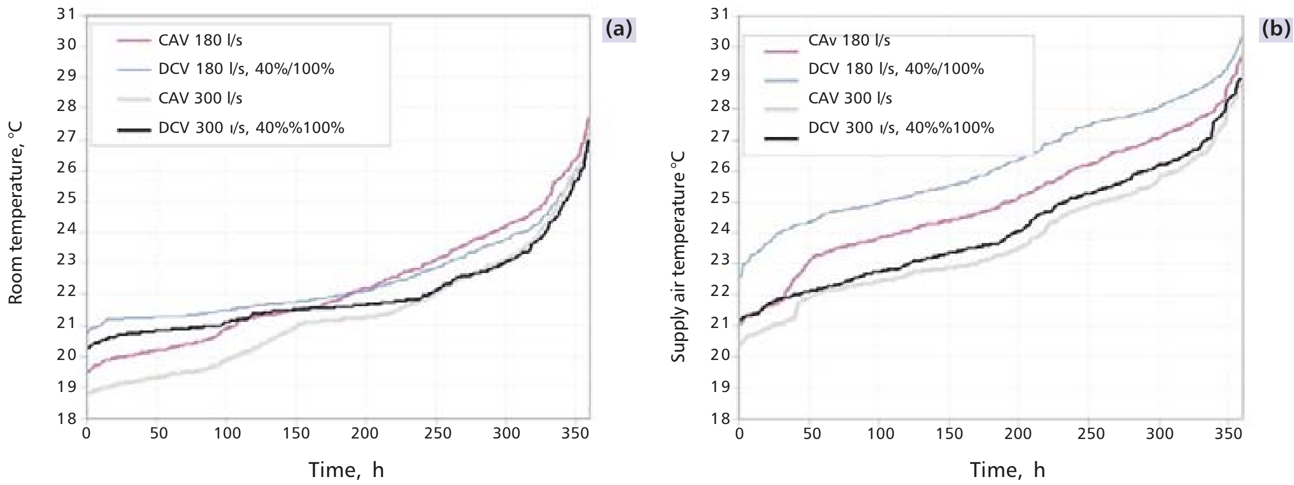

Figure 7. *Summer period room temperature duration curves in the south classroom, (a) and in the north classroom, (b)*

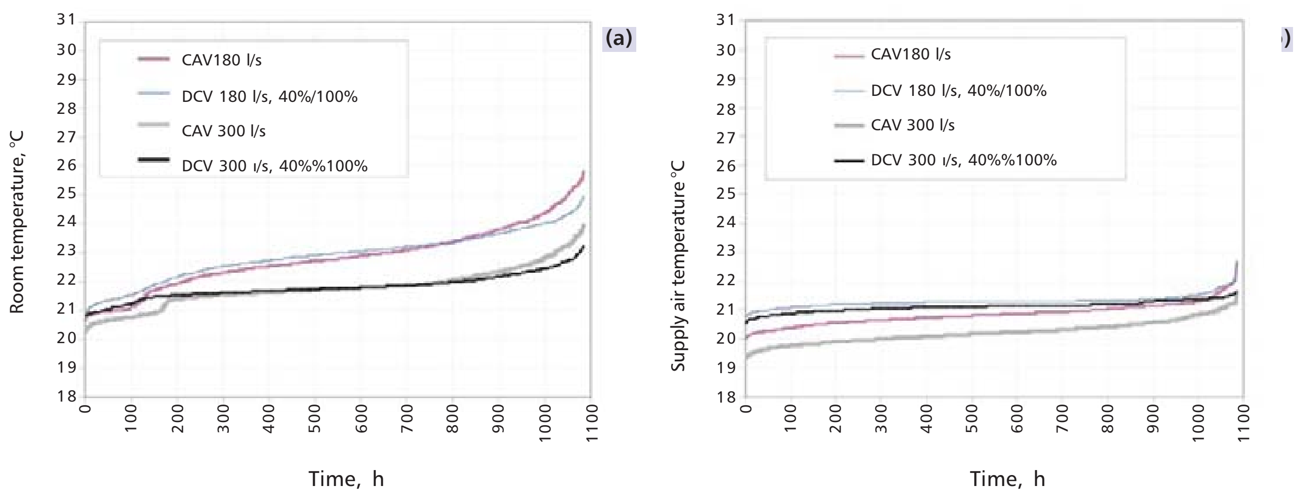

Figure 8. *Heating season room temperature duration curves in the south classroom, (a) and in the north classroom, (b)*

CAV system and DCV system with CO_2 and temperature control was simulated. DCV system had two air flow steps, 100% and 40% of total airflow. The results are shown in ***Figure 7*** for the summer period and in ***Figure 8*** for the heating season. With night time ventilative cooling the summer period temperatures were possible to lower by about 1°C from values shown in ***Figure 7****.*

4. Discussion

Measured supply air flow rates were significantly lower than design values in three schools out of six. Due to relatively low occupancy the airflows per person were still sufficient, 6 L/s per person or more in all schools and CO_2 concentrations were less than 1200 ppm. Room temperature measurement results show a typical problem with temperature control as at the end of the heating season the temperatures up to 25°C were measured. Simulated results show that this problem can be avoided without mechanical cooling if high enough ventilation rates and cool supply air is used. In the majority of the schools measured, ventilation rates were too low and supply air too warm for effective control of the room temperature.

Air velocity measurements showed remarkable differences between air distribution schemes. Duct and ceiling diffusers showed good performance with a maximum velocity less than 0.2 m/s and can be highly recommended for classrooms. The duct diffuser in A without nozzles (just a perforated duct) showed worse performance with a maximum velocity of 0.29 m/s. The wall diffusers were clearly not suitable for classrooms due to high velocities up to 0.43 m/s. Displacement ventilation diffusers were very sensitive to supply air temperature, as a temperature difference of 3°C caused velocities up to 0.28 m/s.

The parametric simulations showed the effect of high internal gains: high supply air flow rates up to 10 L/s per person and cool supply air down to 14-15°C was needed for room temperature control. However, mechanical cooling was not needed in the classrooms as schools are normally not used during summer holidays. DCV ventilation showed better performance in terms of thermal comfort when higher simulated airflow rate of 300 L/s per classroom was used. At lower airflow rate of 180 L/s the classrooms were less overheated with CAV ventilation. It was shown that a DCV system supplying 10 l/s per student and 300 L/s per classroom combined with night-time ventilative cooling ensured good temperature control in fully occupied as well as partly occupied classrooms. A similarly sized CAV system cooled down classrooms with low occupancy, thus, demanded additional heating of the supply air in classrooms. Air flow rate of the lower indoor climate category, 6 l/s per student and 180 L/s per classroom, resulted still tolerable but significantly higher temperatures, often above 23°C in the heating season.

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