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A COMPARATIVE STUDY OF DIFFERENT AIR DISTRIBUTION SYSTEMS IN A CLASSROOM

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ABSTRACT

This study involves comprehensive experimental measurements and CFD simulations in a mock-up of a full-size classroom with realistic loads. Four different air distribution systems have been tested:

- Mixing ventilation produced from a high velocity ceiling supply device
- Bag-supply (textile) device located in the ceiling
- Displacement ventilation using a standard low velocity air supply device
- A down-to-floor impinging jet air supply device.

The measured wall temperatures have been used as boundary conditions for the CFD simulations. Predicted and measured quantities are: air velocity, air temperature, ventilation effectiveness and local mean age of air.

The down-to- floor impinging jet was also tested in a field trial.

KEYWORDS

Air distribution methods, School Ventilation, Full-Scale Measurements, CFD, Impinging jet

INTRODUCTION

In Swedish schools, the number of students per square metre of floor area has increased during the last decade. This increase in heat load has caused indoor climate problems in schools and designers are trying to find new devices and ventilation strategies that can cope with the new and challenging situation. Ventilation systems that have been designed for other applications may not perform well in school buildings. When designing a ventilation system, a number of different concepts must be evaluated. Therefore, one needs to follow the following steps:

- Comparison of all available systems under the same but new operating conditions.
- Evaluation of the advantages and disadvantages of each system.
- Implementation of the results of the study in a real design.

Not only an effective filtering methodology, which eliminates harmful particles in a ventilated room, but also the principle of reliable air distribution system is of vital importance in ventilation. As a result of the increase in particulates responsible for human allergy in modern living, the traditional high momentum mixing ventilation system, which supplies the air from the ceiling level, is questioned more and more. The displacement ventilation, which supplies the air from the floor level as a gravity current appear to be a promising method for providing a good air quality. It is worth mentioning that for most ventilation applications the air supply from floor level ,except for operating theatre ventilation (Friberg et. al, 1996), peforms well.

When the concept of ventilation efficiency was first introduced by Sandberg (1981) more than a decade ago, ventilation system designers and manufacturers began to pay attention to the efficiency of their systems. As a reference, a system with an air -exchange efficiency larger than 40% is regarded as an acceptable system. Although the traditional mixing system seldom exceeds the limit of 50% efficiency, this method is still a dominant ventilation strategy in most buildings.
The promising results from displacement ventilation showing efficiencies higher than 50% have encouraged people to use this method. However, by measuring the local exchange indices, as a measure of air quality, surprisingly displacement systems often show poor efficiency in some parts of the room. This appears to be due to the imbalance between the thermal (buoyancy) forces and momentum forces. To overcome this problem new systems have been developed, see Fig. 1.

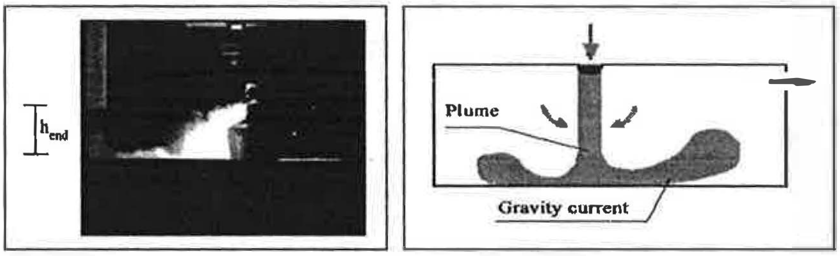

Figure 1: Primary airflow pattern generated by down-to-floor impinging jet and textile supply devices

These systems have the following properties:

Jet impinging directly on the floor - The supply device is in fact the duct itself which ends at a certain distance, h_{end} , above the floor. The jet is supplied with lower velocity (momentum) than jets from mixing ventilation devices. They are therefore called medium momentum supply devices. This method combines some positive effects of both mixing and displacement systems. It produces a clean zone in the lower part of the occupied zone and exhibits a higher air-exchange efficiency than a mixing system, i.e. it is similar to displacement ventilation. At the same time it has some of the properties of mixing ventilation by causing entrainment of the ambient air into the jet. Another advantage is that heated air can be supplied with this system in contrast to displacement system. The somewhat higher velocities generated by this system very close to the floor can be challenging from thermal comfort considerations. Howevere, there are indications of that the number of particles in the air is less than the traditonal supply devices (Stridh, 1998) and allergical substances in the air produce in this system seems to be less (Jonsson, 1977).

Bag (textile) systems located in the ceiling - The bag supply device is a low velocity device located at ceiling level. A typical supply velocity in this case is less than 0.1 m/s. The supply device can be taken away and cleaned as required.

METHODOLOGY

When we compare the performance of these systems we use a combination of full scale measurements and CFD predictions. To obtain the best possible out of both methods the full-scale tests have been used to provide boundary conditions for CFD predictions, see Fig. 2 (where **P** is the heat load and $\mathbf{q_v}$ is the ventilation flow rate).

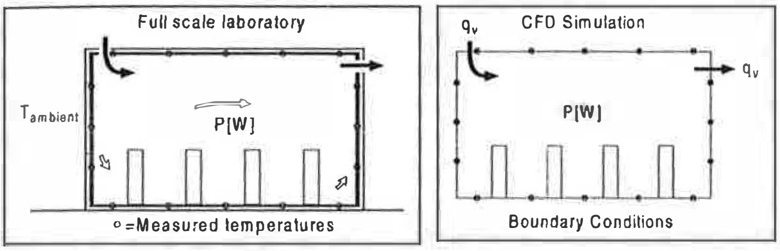

Figure 2: Method of CFD modelling

Finally, to demonstrate that the system performs satisfactorily in practise, field trials in a school building were carried out.

EXPERIMENTAL SET-UP

The floor area of the mock-up is 60 m^2 (see Fig. 3) and the ceiling height can be varied continuously up to 5.2 m. In all tests, the ceiling height was kept at 3 m. To produce a heat-load corresponding to a fully occupied classroom 25 person-simulators were placed in the room. The classroom has an "outdoor facing" wall, provided with four triple glazed windows, located next to a temperature controlled room whose temperature can be varied to simulate winter and summer climates. No heaters below the windows have been used for winter conditions. The heat load consisted of 25x 95 = 2375 W generated by people and 525 W generated by lighting giving a total load of 2 900 W (48 W/m^2). In all tests the air flow rate was 10 l/s per person and the inlet air temperature was kept constant at +15°C. The outdoor temperature was kept at –21 °C to simulate winter conditions and at + 25 °C to simulate summer conditions. These are somewhat extreme conditions as in practice the winter supply temperature should be higher than +15 °C, but the purpose of the study was to test the systems under such extreme conditions in order to be able to identify differences in performance. All measurements were carried out under steady state conditions.

The devices were tested by measuring the air temperature, air velocity and air quality (local mean age of air) in the occupied zone. At points 1-12, temperatures were measured at heights of 0.1, 1.2, 1.8 and 2.25 m above the floor; velocities for 0.1 and 1.2 m above floor. The local mean age of air was measured by using tracer gas technique (decay method) at 1.2 m above floor.

CFD CALCULATIONS

The numerical simulations were done using the CFD code VORTEX (Awbi, 1996) that has been developed for the simulation of airflow, heat transfer and concentration in enclosures. The code uses the standard κ-ε turbulence model. The program has been developed for ventilation research, which may be more suited to ventilation simulations than the more general-purpose codes. In the simulations, the measured mean surface temperatures of all six room surface have been used as boundary conditions. The number of nodes used were 38 x 35x 28 giving a resolution of 0.22 m in the horizontal plane and 0.11 m in the vertical direction. The near-wall nodes were located 10mm from the surfaces as recommended by Awbi (1998). The distance from the floor level for impinging jet was 0.95 m as in measurements.

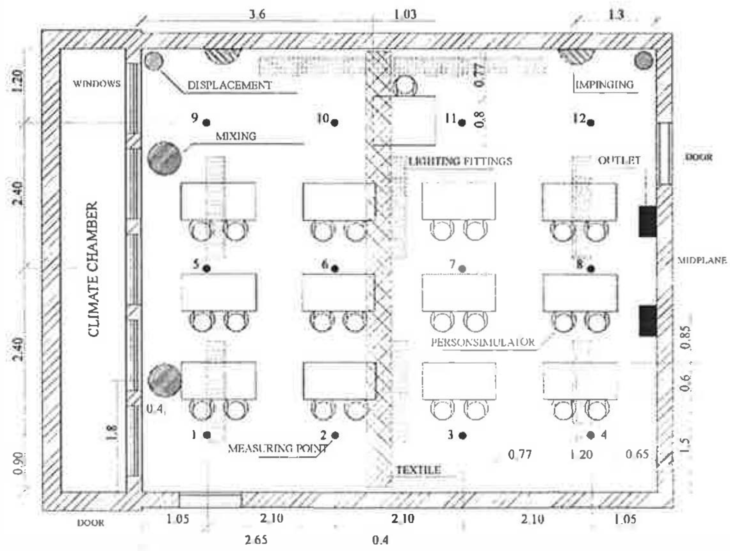

Figure 3. Plane view of the classroom with supply positions. All dimensions in meters.

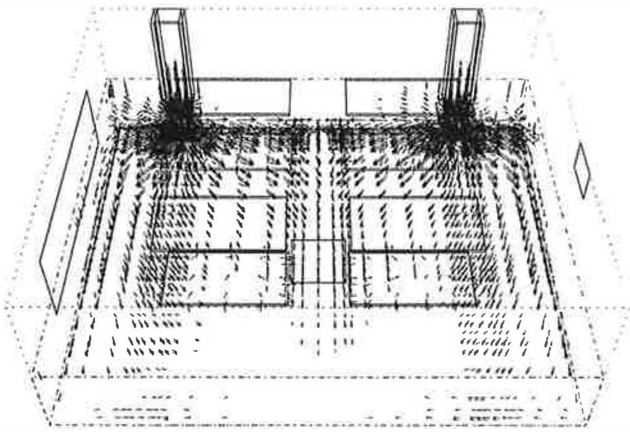

Figure 4. Prediction of velocities of down-to-floor impinging system at winter conditions.

RESULTS

Laboratory Tests and CFD Predictions

Figure 4 shows the general flow pattern in the classroom with the down-to-floor impinging jet system. Table 1 gives some comparisons between measured and predicted velocities at 4 points in the room. From this table one can see that the overall agreement between the measured and predicted (CFD) velocities are good.

TABLE 1

VELOCITIES [m/s] FOR POINTS 5, 6, 7 AND 8 AT A HEIGHT 0.1 m ABOVE THE FLOOR

Stand no.	5		6		7		8		Case
System	Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured	Predicted	
Mixing	0.23	0.23	0.13	0.17	0.16	0.06	0.14	0.10	Winter
	0.11	0.10	0.18	0.08	0.17	0.11	0.11	0.14	Summer
Displacement	0.12	0.13	0.11	0.11	0.11	0.10	0.14	0.14	Winter
	0.14	0.07	0.11	0.09	0.12	0.11	0.14	0.10	Summer
Impinging jet	0.09	0.12	0.15	0.11	0.10	0.11	0.11	0.12	Winter
	0.14	0.12	0.11	0.10	0.11	0.11	0.12	0.12	Summer
Textile	0.11	0.10	0.22	0.16	0.17	0.17	0.08	0.09	Winter
	0.13	0.06	0.13	0.12	0.30	0.17	0.14	0.12	Summer

The discrepancies between the measured and predicted velocities for some of points and particularly for the summer condition, may be due to a number of following reasons:

- Simplifications in the modelling of the real enclosure for the CFD solution
- The presence of strong buoyant flows which cannot accurately be represented by the standard κ-ε model
- Weakness of the wall functions used in the CFD code
- The influence of local buoyant flows, particularly in low velocity regions, on the measuring instruments
- Errors in measurements.

However, the CFD program gave very promising results. This is probably due to that the measured surface temperatures have been used as boundary conditions in the CFD model. The program is also capable of predicting thermal comfort conditions (because it has a radiation model), the age of air and ventilation effectiveness.

TABLE 2

EXPERIMENTAL AIR EXCHANGE EFFICIENCY AND LOCAL MEAN AGE OF AIR

System	Local mean age [minutes]				Air exchange efficiency [%]	Case
Stand no.	5	6	7	8		
Mixing	-	-	-	-	-	Winter
	13.0	12.5	12.5	12.5	47	Summer
Displacement	14.4	11.1	9.5	6	49	Winter
	5.3	6.6	5.6	5.2	62	Summer
Impinging jet	16.0	12.7	8.4	8.7	48	Winter
	8.5	6.6	6.8	7.9	60	Summer
Textile	11.5	10.6	11.2	11.6	50	Winter
	11.9	12.1	12.1	11.5	48	Summer

Results from field trial

The down-to floor impinging jet system (h_{end} = 0.90 m) was installed in a school (Strömsbro Skolan in Gävle) and the air-exchange efficiency was measured in the extract duct with a tracer gas technique. In the summer case, the supply flow rate was 255 l/s and the supply temperature was + 18 °C. With no students present the air-exchange efficiency was 62 % and with 24 students present this was lower at 54 %.

CONCLUSIONS

The results obtained in this study can be summarised as shown in the following Table 3.

TABLE 3. SUMMARY OF RESULTS

Supply type	Temperature		Velocity		Air distribution		Noise level
	Summer	Winter	Summer	Winter	Summer	Winter	
Mixing	Uniform	Uniform with lower flow rate	High in some zones in the occupied zone	As the summer case	Acceptable	Acceptable	Some noise
Displacement	Somewhat lower near the floor and supply outlet	Like summer but lower temperature difference vertically.	Somewhat high near supply but very low over the floor	As the summer case	Acceptable everywhere	Not so good close to windows	Silent
Impinging jet	Somewhat lower near the floor and supply outlet	As summer case but lower temperature difference vertically	Somewhat high near supply but very low over the floor	As the summer case	Good	Not so good close to windows	Silent
Textile	Uniform	Uniform vertically, lower near the window	Dropping down directly under the supply	Somewhat lower than in summer	Acceptable	Acceptable	Silent

As seen each system has its pros and cons. Systems with a direct supply of air into the occupied zone are efficient ventilation systems but restrict the use of floor area close to the location of air supply devices. Mixing ventilation systems are somewhat less efficient and may be somewhat noisier but do not restrict the use of the floor area.

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