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# Velocity variations in ventilated rooms as a method for creating comfort

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## Abstract

The aim is to develop a new method for comfort in settings with high thermal load in buildings that do not require continuos cooling but cooling only during shorter periods. Example of such buildings is schools. The present ventilation and control systems are designed for supply of air at a constant flowrate or to respond to relatively slow variations in load or step changes in load. The slow variations in load are mainly governed by the diurnal cycle and sudden step changes in load are mainly due to people entering or leaving a room. Systems of today are monotonous in the sense that the indoor climate is kept almost constant over long periods. However, there are indications that intermittent variations in velocities can be beneficial to people's perceived comfort. For example when people feel too warm the introduction of a short “breeze” of "high velocity" air may make them feel more comfortable. One example is window airing. The use of (non-turbulent) variations as a stimulus for creating comfort has not as yet been explored systematically or been technically implemented. The idea is to create velocity variations in the head region on people. Both momentum (mixing ventilation) and pure buoyancy driven (displacement system) ventilation are used for creating velocity variations. In addition to using the ventilation system for introducing velocity variations, stirring generated by propellers (ceiling fans) are used. The paper reports on the velocity field obtained in the occupied zone.

**List of symbols**

$C_p$ = specific heat at constant pressure [kJ/kg K]

$\bar{u}$ = mean velocity over time [cm/s]

$<\bar{u}>$ = mean value of the sensors located in the occupied zone [cm/s]

I = relative turbulence intensity ($I = \sigma/\bar{u}$ x100 [%])

$<I>$ = mean value of I in the occupied zone [%]

$\beta$ = coefficient of thermal expansion [1/K]

$\sigma$ = standard deviation of the turbulent velocity fluctuations [cm/s]

$\rho$ = density [kg/m$^3$]

## 1. Introduction

Despite a relatively severe winter climate the need of cooling of buildings in Sweden is a growing problem. Cooling is very expensive and the cooling process requires a substantial amount of energy. Therefore there is a need of reducing the need of cooling. In search for methods that can contribute to this, the aim is to develop a new method for achieving thermal comfort. The idea is to create velocity variations in the head region on people, because that part of a normally dressed human is the most sensitive one.
These types of methods can be implemented in any buildings provided with a mechanical supply ventilation system equipped with a computerised control system. One group of

buildings particular amenable for using this technique are buildings not provided with any cooling system. Examples of such buildings are schools, which under some periods (late spring and early autumn) very often suffer from overheating.
Present systems are not designed to create intermittent variations. However, there are indications that intermittent variations in velocities can be beneficial to people's perceived comfort. For example when people feel too warm a short “breeze” of "high velocity" air may be a relief which is positive for the sensation of comfort. It is well known that people, when the room air is too warm, usually like window airing during shorter periods. The use of variations as a stimulus for creating comfort has not as yet been explored systematically or been technically implemented. It is our hypothesis that it is not only the cooling effect people like but also the fact that a change in the climate is introduced. Furthermore the hypothesis is that by introducing variations people’s sensation of a pleasant indoor climate can be met at higher room temperatures than otherwise. Therefore there is a potential to save energy. The following methods will be used for creating velocity variations.

Method 1. Alternating between supply of air with displacement system and mixing ventilation system. The flow rate is kept constant.

Method 2 . Using mixing ventilation and alternating between high and low flow rates.

Method 3. Supplying air with the displacement ventilation system keeping the flow rate constant and running the ceiling fan on off.

This work is a part of a project where human's response to non-turbulent velocity variations will be explored. The variations will be introduced in the whole room.The project is subdivided into two parts; a pure technical part and an experimental part where test persons are exposed to controlled velocity variations. The aim for the technical part is to create time-controlled velocity variations that later will be used in the experimental part were groups of test persons participates. In those tests human emotion, cognitive performance and thermal comfort will be measured.
This paper reports on the first findings from the pure technical part of the project.

## 2. Theoretical relations between the velocities at the primary air sources of air motion and the velocity in the occupied zone

Only air motions generated by a single source are dealt with and we assume isothermal conditions. In a room with many sources there are interaction effects caused by merging air streams and colliding air streams. In addition to these effects related to the primary air streams there are airflows along the room surfaces generated by heat transfer. These air streams may either assist or counteract the flow generated by the primary sources.

### 2.1 Air motions generated by momentum sources

As momentum sources for generating air motions we use

1. Supply of ventilation air through high velocity devices intended for mixing ventilation

2. Propeller (Ceiling fan)

The momentum generated by both sources can formally be written in the same form

$M = \rho QU(0)$ [N] (1)

Where in case 1 the flow rate Q is equal to ventilation flow rate, the area A is the free opening area of the supply device and the initial velocity U(0) =Q/A.
With this notation the momentum generated by a supply device can be expressed as

$M=\rho AU(0)^2$ [N] (2)

A propeller accelerates the air from zero to a maximum velocity. For an ideal propeller (actuator disk) the maximum axial velocity is twice the velocity through the propeller. We set A to be the area obtained of the disk located inside the circle generated by the rotating tips of the propeller blades and U(0) is the maximum velocity generated downstream of the propeller. It follows that Q=1/2U(0)A. With this notation the momentum imparted on the air can be written as

$M= 1/2\ \rho AU(0)^2$ [N] (3)

Both sources of momentum give rise to turbulent jets, which propagates into the room and grows in size as it entrains ambient air. The air leaving the propeller has a rotary motion about the propeller axis, in addition to its axial motion. Therefore the propeller generates a swirling jet. It is known that a swirling jet has a higher entrainment rate than a non-swirling jet.

For isothermal jets the only velocity scale is U(0) and therefore we shall expect that the velocity, $U_x$, at location x in the occupied zone is proportional to U(0)

$U_x = k_M(x)U(0)$ [m/s] (4)

Where $k_M(x)$ is a room dependent constant at a particular location x in the occupied zone. From the above relationship if follows that the velocity in the occupied zone will change proportional to the supply velocity. The constant is relatively small, with a target velocity in the occupied zone equal to 0.15 m/s the constant will at supply of air with high velocity devices be in the range 0.02-0.05.

**2.2 Air motions generated by pure buoyancy sources**

Supply of cold air with a low velocity device located close to the floor give rise to a gravity current which is characterised by its buoyancy flux B[$m^4/s^3$]. The buoyancy flux can either be expressed in term of the heat load P [W] to be removed or alternatively in terms of the ventilation flow rate and the temperature difference ΔT between the room temperature and the supply air temperature.

$$B = \frac{g\beta P}{\rho C_p} = Qg\frac{\Delta T}{T}$$ [$m^4/s^3$] (6).

If we have a characteristic room width W a velocity scale in the occupied zone is

$$U_x = k_B(x)(\frac{B}{W})^{1/3} \qquad [\text{m/s}] \qquad (7)$$

The last expression highlights that, due to the presence of the exponent 1/3, it is very difficult to change the velocity. A change of B by 100 % does only change the velocity by about 25 %. The constant $k_B$ can close to the supply device be larger than one and will at some places in the room be equal to1, see section 8.9.2 in Etheridge and Sandberg, 1996.

## 3. Facilities

### 3.1 The "classroom"

All measurements were carried out in a test room of the size of a classroom (Figure 1 to 3). The classroom is well insulated and is situated in a laboratory hall (Mattsson, 1999). See also (www.hig.se/bmg). The room is furnished with tables and chairs for 25 persons. The lighting consisted of nine fluorescent tube fittings, each with the power of 56 W, which were mounted at the false ceiling. The ceiling fans and the inlet terminals for high velocity air are located between the ceiling and the false ceiling. The false ceiling is a grating. The goal is to create "normal" environments for the test persons who are going to be involved at a later stage. Only standard ventilation components have been used. The "high velocity" supply devices are terminals provided with nozzles whose orientation can be adjusted individually. The ceiling-fans have four blades with a total diameter of 1050 mm.

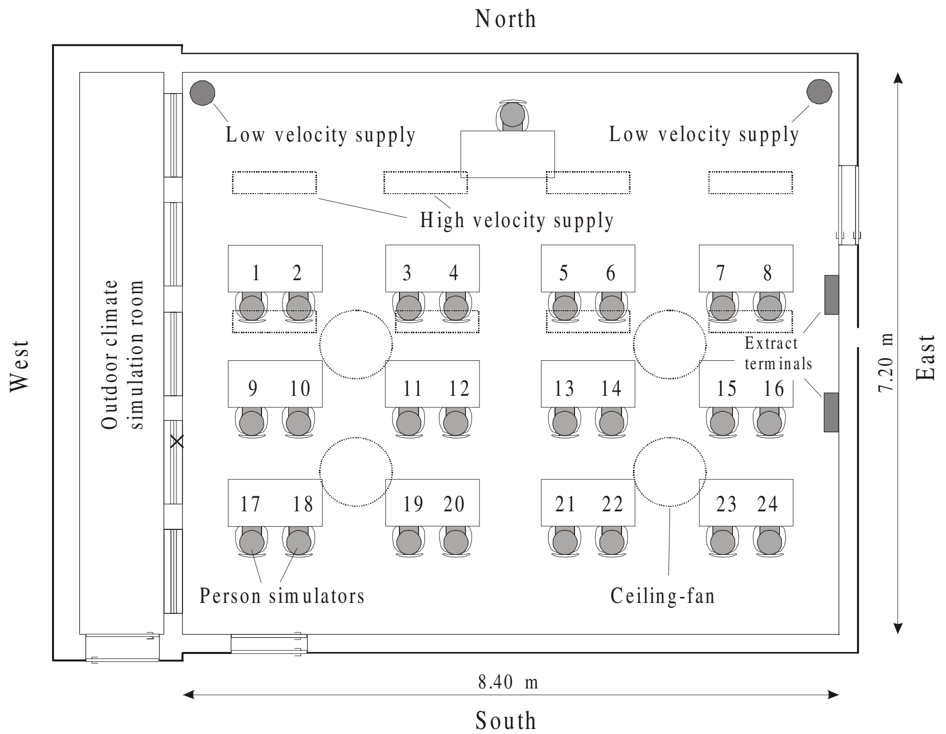


**Figure 1**
Physical set-up for the classroom.

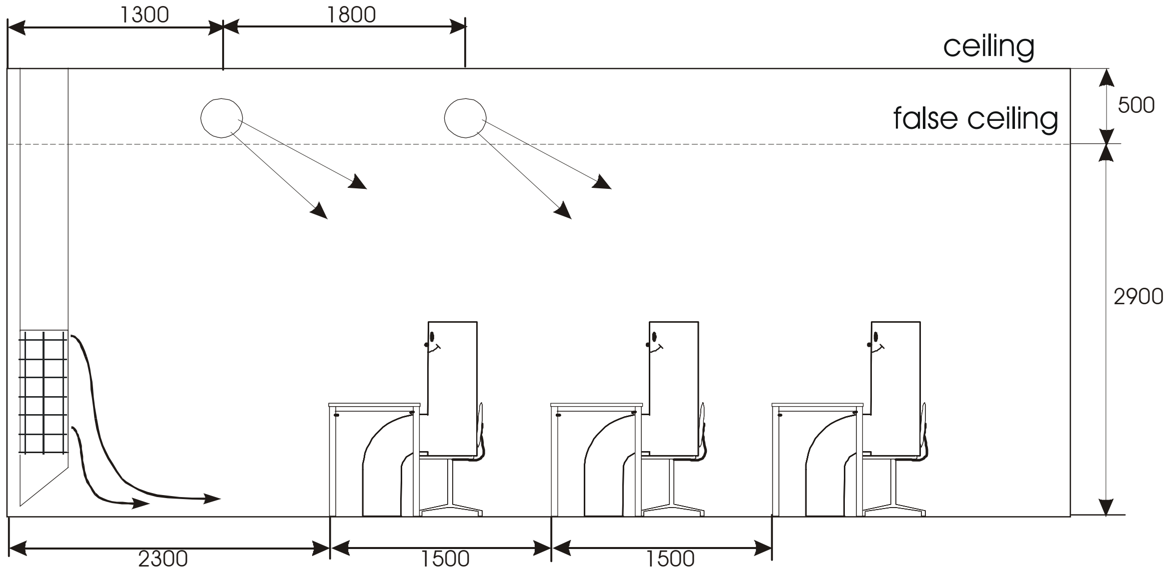


**Figure 2**
Side view of classroom. Set-up used for method 1 and 2.
Dimensions in mm

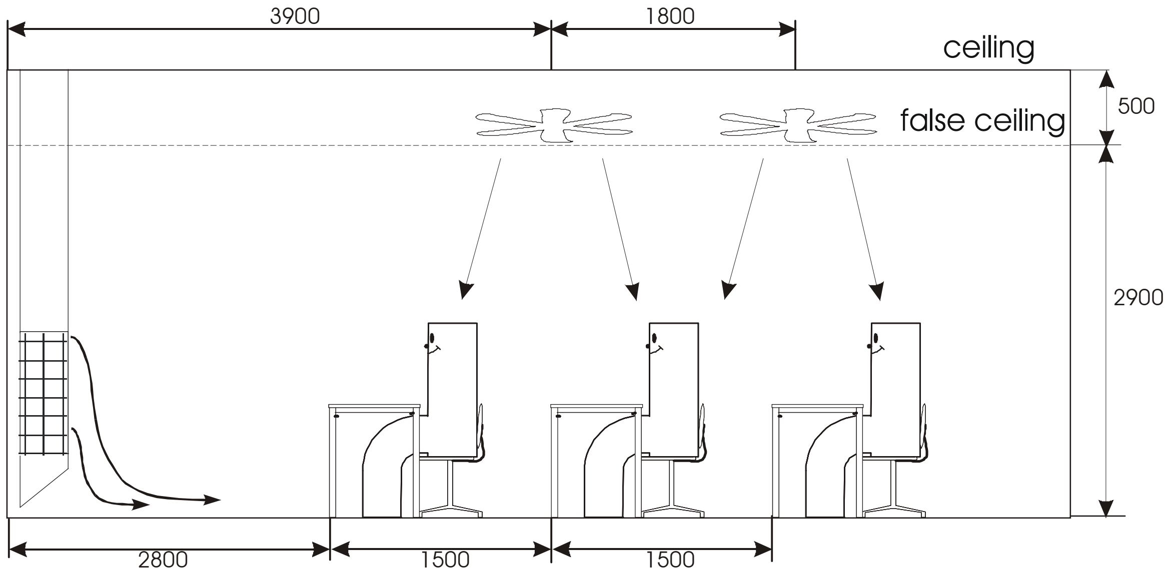


**Figure 3**
Side view of classroom. Set-up used for method 3. Dimensions in mm

### 3.2 The person simulators

In order to simulate thermal loads in the classroom person simulators were used. A person simulator (PS) is a textile covered metal tube that is electrically heated by five power resistors (Figure 4). The heat emission from each PS was 95 W (Mattsson, 1999).

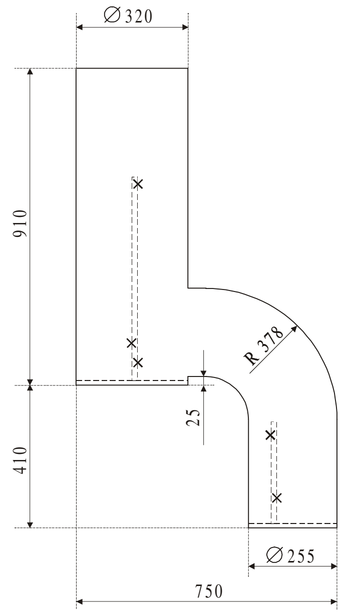


**Figure 4**
Drawing of a person simulator
The power resistors are marked with “x”. Dimensions in mm.

### 4. Velocity measurements

The velocities are measured with omnidirectional thermistoranemometer CTA88 (Lundström et al. 1990). The anemometers has been calibrated within the range between 0.05 and 1.0 m/s with an uncertainty of +/-(5% + 0.03 m/s). The velocities are measured at one point in front off the PS (Figure 5) with a sampling frequency of 1 Hz and a measuring time of 3000 seconds, for every 24 PS.

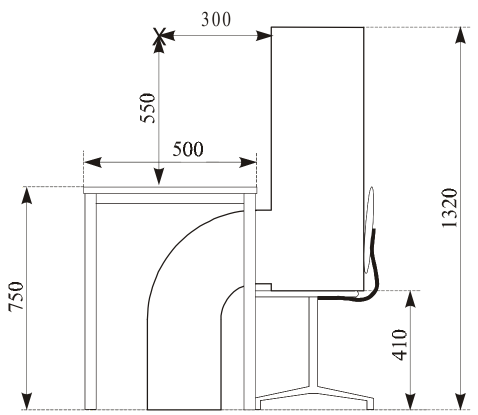


**Figure 5**
Person simulator seated by a bench. “X” marks the point for measurement of velocity. Dimensions in mm.

## 5. Experimental set-ups

The velocities are measured under realistic conditions, which means that the classroom is equipped with furniture for 25 person (24 students and one teacher) and there are 25 person simulators. The simulators (25*95 W) and lightning (18*28 W) gives a thermal load of 48 [W/$m^2$ floor area]. When the measurements start the room and the supply air have a temperature of +21°C. During the measuring time, 3000 seconds, the average temperature in the classroom rise to +25°C. Common for all three methods is that the inlet temperature is constant and the experiment starts with 1200 seconds of "low velocity" conditions followed by 300 seconds of "high velocity" conditions, which is repeated once. The choice of 1200 seconds is to achieve stabile conditions. For the "high velocity" period it is a compromise between creating a short "breeze" and to be able to measure stable mean value.

Method 1: Flowrate 200 l/s. Starting with supply air at floor level (displacement system) then switching to supply air at ceiling level (mixing system).

Method 2: Air supply at ceiling level. Starting with 150 l/s then switching to 250 l/s.

Method 3: Air supply at floor level. Flowrate 200 l/s. Starting with the ceiling-fan turned off then turn it on.

## 6. Results

First of all displacement system was tested. Flow-rates between 100 – 400 l/s combined with under temperature up to 5°C were used. The result was that the velocity in the head region did not change. This was the expected result.

### 6.1 Method 1- Alternating between displacement ventilation and mixing ventilation. Flow rate constant

The mean velocity, $\bar{u}$, for the "high velocity" period varies from 8 cm/s to 20 cm/s at different positions (Figure 6). The relative turbulence intensity, <I>, was 43 %.
The average value $<\bar{u}>$ in the occupied zone was 12 cm/s. For the "low velocity" period the $<\bar{u}>$ lies below 6 cm/s.
Figure 7 shows the whole time series for one measuring point.

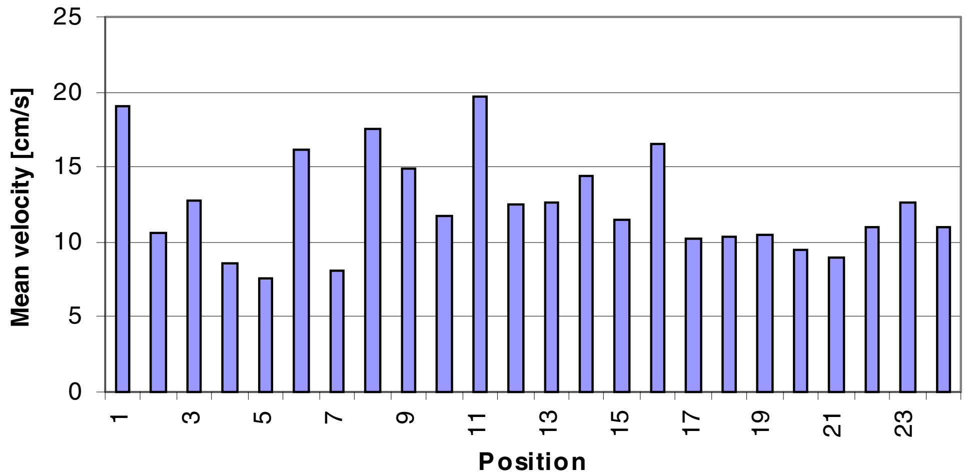


**Figure 6**
Mean velocity for the "high velocity" period at different positions. Method 1.

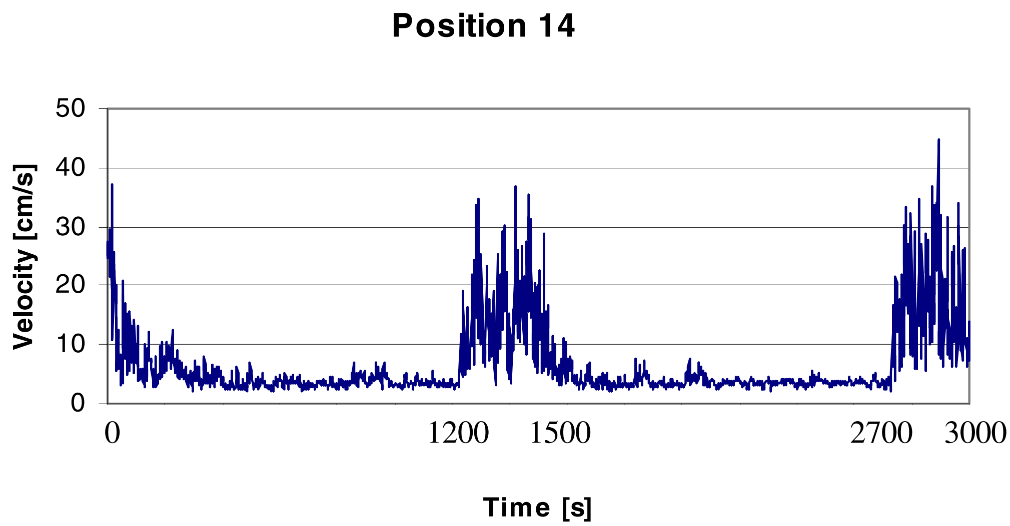


**Figure 7**
Velocity at position 14. Method 1.

### 6.2 Method 2- Mixing ventilation changing flow rate

The mean velocity, $\bar{u}$, for the "high velocity" period varies from 8 cm/s to 20 cm/s at different positions . The relative turbulence intensity, <I>, was 43 %. The $<\bar{u}>$ during the "high velocity" period was slightly higher, 12 cm/s. (Figure 8 and 9) In some positions there was no significant difference in $\bar{u}$ during the "low-" and "high velocity" period. The $<\bar{u}>$ during the "low velocity" period was 9.6 cm/s.

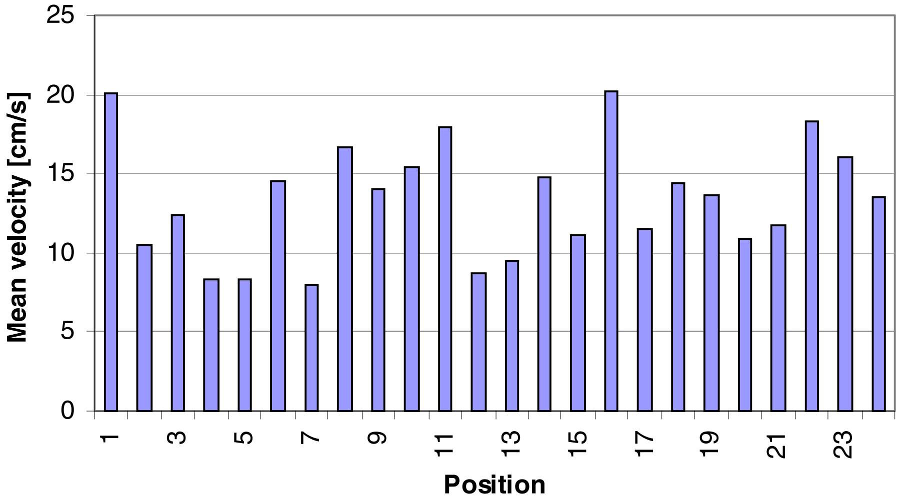


**Figure 8**
Mean velocity for the "high velocity" period at different positions. Method 2.

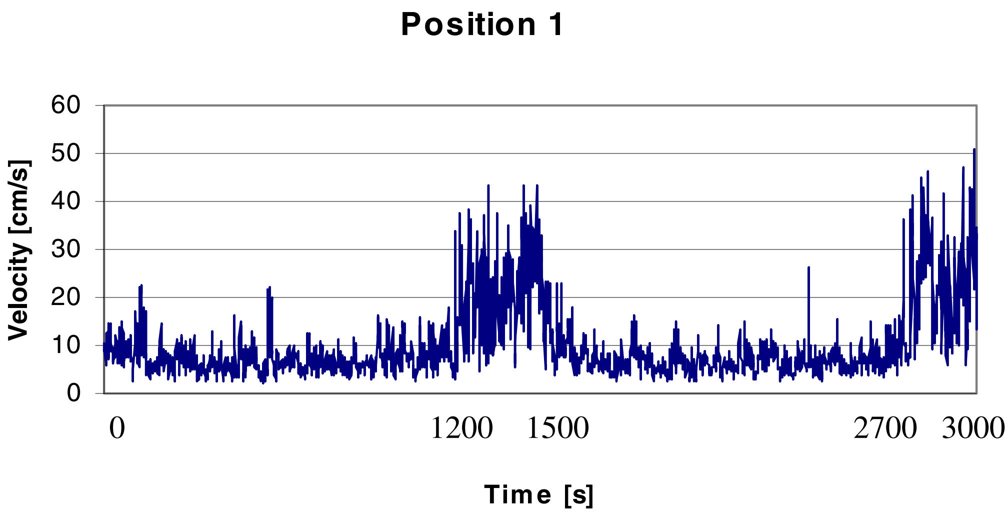


**Figure 9**
Velocity at position 1. Method 2.

### 6.3 Method 3- Alternating between displacement ventilation and stirring with a ceiling fan

With this method it was a large difference between the largest $\bar{u}$, 45 cm/s, and the smallest, 9 cm/s. For the "low velocity" period the $<\bar{u}>$ lies below 6 cm/s and during the "high velocity" period the $<\bar{u}>$ is 17 cm/s. The relative turbulence intensity was 44 %. (Figure 10 and 11)

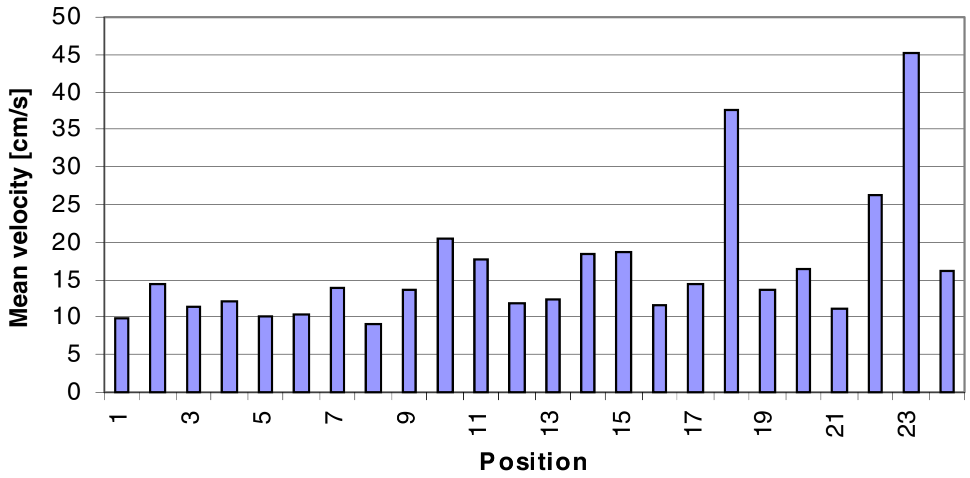


**Figure 10**
Mean velocity for the "high velocity" period at different positions. Method 3.

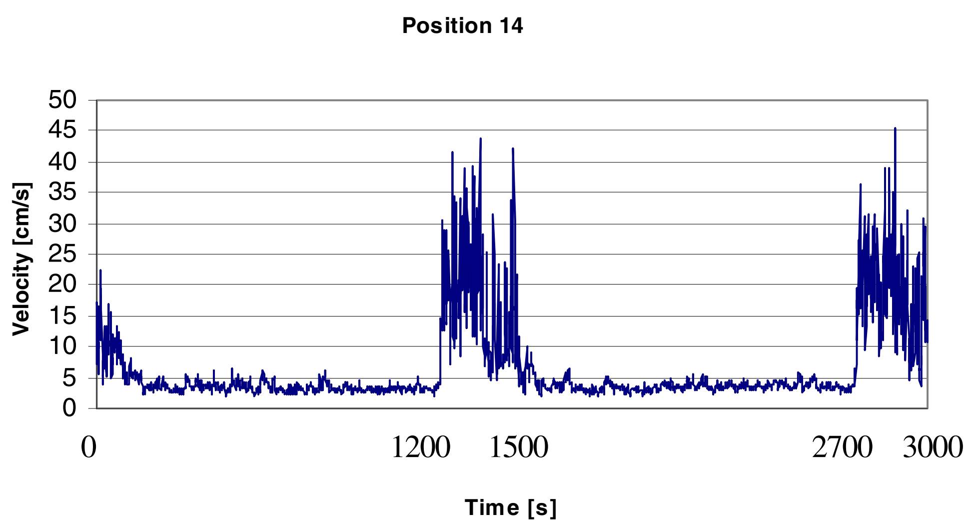


**Figure 11**
Velocity at position 14. Method 3.

## 7. Conclusions

- It is not possible to create any velocity variations by using displacement ventilation only.

- A marked change in velocity was obtained by either switching between displacement- and mixing ventilation (Method 1) or using displacement ventilation and running a ceiling-fan on/off (Method 3).

-The average relative turbulence intensity, 43 %, was obtained by generating the velocity by a propeller (ceiling-fan) or a high velocity ventilation supply terminal.

- The recorded response ( mean velocity) to a change was non-uniform in the occupied zone. However, these measurements do not give the complete picture of the velocity field. There are also large-scale fluctuations and therefore people might sense a difference at each position.

- Method 1 and 3 creates velocity variations using constant flowrate. One advantage is that this doesn't require any speed control of the supply- and extract fans.

- The methods requires the use of time-controlled sequences. Today's ventilation control system doesn't have this function implemented and therefore some development of the control systems is required.

## Acknowledgements

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