Egorov Artem
T662KA

Displacement ventilation in lecture halls

Bachelor's thesis
Building services

December 2012

MIKKELIN AMMATTIKORKEAKOULU
Mikkeli University of Applied Sciences

DESCRIPTION

MIKKELIN AMMATTIKORKEAKOULU Mikkeli University of Applied Sciences	**Date of the bachelor's thesis** 13.12.2012
Author(s) Artem Egorov	**Degree programme and option** Building services

Name of the bachelor's thesis

Displacement ventilation in lecture halls

Abstract

This thesis considers several important goals. The main purpose is to see how displacement ventilation system works in the lecture hall of M-building and compare obtained results with D2 and Indoor Climate Classification. The second one is to analyze the function of the ventilation system. The last one is to realize when displacement ventilation is preferable to mixing ventilation.

Analysis of the system was carried out with instruments from MUAS HVAC laboratory. In lecture hall were measured temperature, relative humidity and CO2 concentration in the presence of nearly 50 people and also noise level, velocity and volume of air through the air supply diffusers. All the data are presented in tables and diagrams for easy viewing.

Based on these results it can be concluded that the displacement ventilation system is well suited for a lecture hall. People who are inside get the proper amount of fresh air right under their seats. All of this happens silently and keeps the temperature and relative humidity on wanted level. Air velocities does not exceed the permissible values.

Subject headings, (keywords)

Ventilation systems, displacement ventilation, air distribution

Pages	**Language**	**URN**
33	English	

Remarks, notes on appendices

Tutor	**Employer of the bachelor's thesis**
Heikki Salomaa	

CONTENTS

1. INTRODUCTION

People are always trying to make their lives more comfortable. Indoor climate is a very significant component of our lives. In Europe today, people spend 90 % of their time indoors, so it is important that the air inside should be as clean as possible. History of ventilation began many centuries ago and ventilation systems are always developing. In my thesis, I wanted to show quite new ventilation system – displacement ventilation. This system provides high air quality in occupied zone. Displacement ventilation is the most modern and most efficient ventilation in rooms with high ceilings and heat loads.

1.1Aims

The main purpose of my thesis work is to see how displacement ventilation system works in the lecture hall of Mikpoli and compare the obtained results with D2 and Indoor Climate Classification. My bachelor thesis consists of two parts. First part is theoretical. In this part I wanted to make familiar what is it displacement ventilation, how does it work, pluses and minuses and components of displacement ventilation.

The second aim is to realize when displacement ventilation is preferable to mixing ventilation. During the theoretical part of the bachelor thesis I mostly compare displacement ventilation and mixing ventilation. It is very important to show the difference between these two systems. Displacement ventilation system is not so common like mixing ventilation and I would like to find out its advantages. Also it is necessary to prove that the ventilation type inside the lecture hall is working as displacement ventilation.

1.2 Methods

My methods are literature reviews and measurements in Mikpoli lecture hall. As literature sources I took research works of Mundt and Livchak. They are good experts in the field of displacement ventilation. I used as a literature source also Rehva guidebook «Displacement ventilation in non-industrial premises» and a book of two authors Givov and van Nielsen «Displacement ventilation systems in industrial buildings». First one is a special book with wide choice of examples and useful information about temperature gradient and the second is a product of Russia and Europe cooperation. Also I took some articles from scientific internet sources and ventilation catalogues.

In the practical part of my thesis I measured different parameters which should show how well the system works. Relative humidity, temperature and CO_2 measurements gave information about basic parameters of indoor climate. Air velocity measurements gave possibility to detect drafts under the seats. Noise measurement allowed understand how silently system works. Volume flow measurements gave information about amount of fresh air per each person inside Mikpoli lecture hall. After all measurements I made the conclusion about the work of displacement ventilation. I compared all obtained results with D2 and Indoor Climate Classification during the whole practical part.

2. DISPLACEMENT VENTILATION

2.1 History and researchers

Displacement ventilation was first used in the construction industry in the Nordic countries in 1978. In 1989, it was estimated that displacement ventilation was applied in 50% industrial buildings and in 25% offices in Scandinavia. Applications in other Europe countries have not been as great as in Nordic countries. In U.S were made some research about displacement ventilation. The purpose of research works was to evaluate practicality of application in United States. Studies were needed to understand how the system will operate at different temperatures and climate features, especially humidity. When positive results were obtained displacement ventilation system has been actively used in the U.S. After few years another European countries start actively used this type of ventilation system. /1/

There are some researchers who have done much for the development of displacement ventilation around the world. Mundt concentrated on air quality and different kind of pollutants. Nielsen has focused on air distribution and temperature gradients. Livchak and Nall have researched the capability of displacement ventilation to work in different climate conditions. They have made great progress in the dry and humid climates. Loveday has studied the possibility of combining displacement ventilation systems with chilled ceilings. Melikov has focused on estimation of displacement ventilation functionality.

2.2 Displacement ventilation in educational facilities

Displacement ventilation is an arrangement of air exchange in the room, providing maximum unhindered development of convective flows from the heat source to the upper area of the room. Removing the hot and polluted air from the room, air is carried out from the upper zone and fresh air is delivered to the room in the lower zone at floor level. Displacement ventilation is a tool to provide good air quality in ventilated rooms. Figure 1 shows where displacement ventilation can be used in a University.

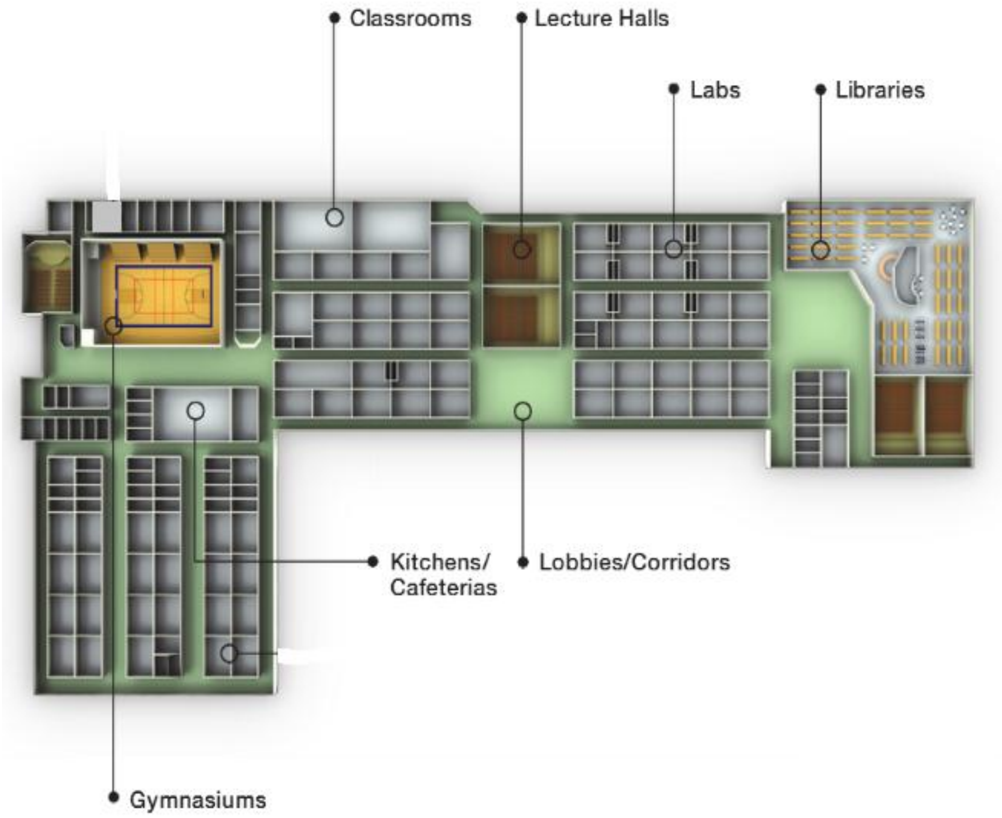

Figure 1.Rooms where displacement ventilation can be used in University /3, p.6/

2.3 Pluses and minuses of displacement ventilation

2.3.1 Advantages of displacement ventilation

The main advantages of displacement ventilation are high quality and low mobility of the air almost in the entire work area. Work of displacement ventilation is especially great in the case when heat and pollution comes into the room from common source. If a pollutant does not produce heat and is located away from heat sources, which forms the convective flows or these flows are not powerful enough and do not reach the level of stratification then the working area can be highly contaminated.

The supply air is not used to control the temperature of the room. Therefore, the air supply systems are characterized by low air flow and simple structure. It helps to save capital costs and reduce energy consumption.

The work area space can be provided with high quality indoor air. Figure 2 demonstrates the difference of air quality in occupied zone.

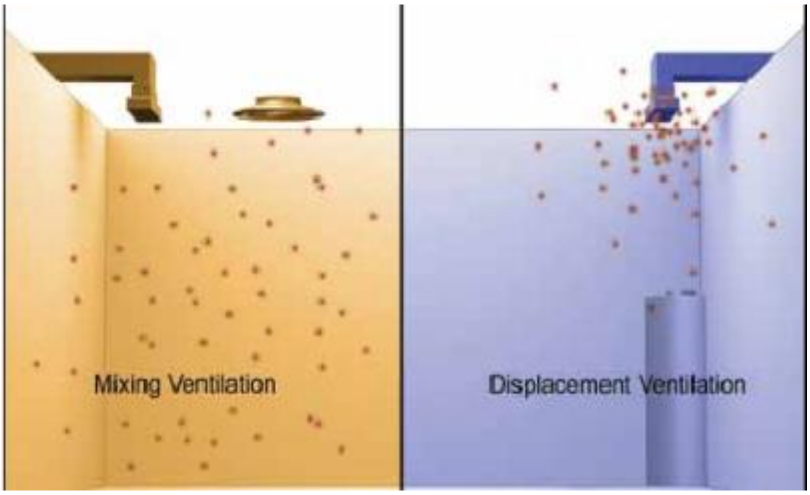

Figure 2.Difference in air quality between mixing ventilation and displacement ventilation

When the supply air system is installed under the floor, local regulation of the supply air flow can be easily controlled by changing the position of floor diffusers.

In mixing ventilation temperature is the same everywhere. When displacement ventilation is used, the indoor temperature rises from floor to ceiling. This means that the working area is the most comfortable part of the room. Compared with mixing ventilation, displacement ventilation systems air temperature at the height of the room about three meters is about 1 - 2°C higher. In the high areas temperature is 4°C higher, than in the occupied zone. (Figure 3). This means that when using displacement ventilation, it is possible for longer periods during the year to utilize the free cooling air supply and, consequently, decrease energy consumption for cooling. /2,p.2/

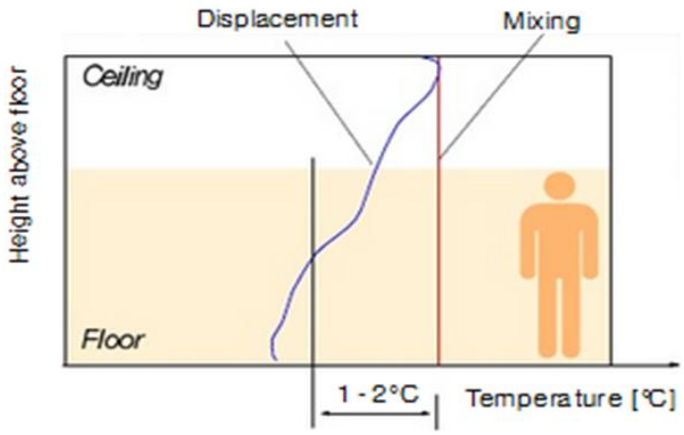

Figure 3.Temperatures in working area of displacement ventilation and mixing ventilation /2, p.2/

2.3.2 Disadvantages of displacement ventilation

To avoid cold drafts on floor area - use only well-regulated air supply system, paying particular attention to the area in front of air diffuser or risk of cold shin increases. In practice, this means that if a cold air comes, should be chosen diffuser, which provides the good proportion of the room air and fresh air.

Diffusers, which are mounted in the lower area of the room, often require a lot of space. The effectiveness of ventilation significantly reduced if supply air diffusers are cluttered.

2.4 Applications of displacement ventilation

Common applications of displacement ventilation are dining rooms of restaurants, conference rooms and lecture halls, classrooms and rooms with high ceilings and big heat loads.

Displacement ventilation is usually preferred in the certain cases. First of all, it is used when contaminants are warmer and / or lighter than ambient air. Secondly, when supply air is cooler than the air in the room. Thirdly, it is used when ventilated rooms have high ceilings, for example, ceilings higher than three meters. Finally, when there is a supply of big air flow rates in a small room.

Mostly offices or rooms where the air quality is not a problem, the best way is to use mixing ventilation. In addition, displacement ventilation may be less favorable to the mixing ventilation in some cases. Firstly, displacement ventilation is not a good choice of ventilation system when the main contaminant in the room is solar heat. Secondly, it is better to use mixing ventilation when ceiling height is less than 3 m and contaminants are colder and denser than indoor air. Thirdly, when there is a need to solve the problem of cooling in low buildings. For example, in offices makes sense to consider the use of chilled beams.

2.5 Design principle of displacement ventilation

Displacement ventilation system design is based on an analytical calculation or on computer aerodynamic models (Computational Fluid Dynamics program). Analytical calculations are used more often. Analytical calculation includes determining supply air flow rate of the system, the distribution of temperature and concentrations of contaminants, convective flows over the heat source in conditions of stratification. Application of CFD-programs can be useful in the design of systems for the different kind of spaces, as the large size of the buildings complicate performance of necessary tests and full-scale measurements, complementing analytical calculations. System projects for such buildings are often unique. However, the practical use of CFD-software for three-dimensional simulation requires certain skill and computer resources, which ordinary designers may not have. In addition, the picture of distribution of temperature and velocity of air by volume space, obtained using CFD, it is not always accurate enough. /4/

Experience shows that the analytical method gives the possibility to obtain a new calculation of the system, which gives good results in most cases. In the analytical method, the designer must determine air flow provided by fresh air system, the distribution of temperature and concentrations of contaminants and convective flows over the sources of heat in the stratification. Table 1 demonstrates calculation sequence of displacement ventilation. /4/

2.5.1 The choice of the ventilation system

Sometimes it is hard to choose between mixing ventilation and displacement ventilation systems. There are some parameters which can help to choose right one. First of all, displacement ventilation can be used for large volumes of air flow, but require enough space for air handling units. As an alternative may be selected floor air devices. Secondly, mixing ventilation is widely used in "normal" areas where the air flow is less 15 l / s, m^2 and the heat load less than 60 W/ m^2 or more. Finally, at small values of the air flow is recommended to use a mixing ventilation in combination with a cooling ceiling. If this was not enough to make a decision Table 2 will help with this. /5/

Table 1.Air distribution system comparison /5, p.4/

	Overhead (Mixing)	Underfloor air distribution (Mixing/Displacement)	Lower wall (Displacement)
Description	Diffusers located in the ceiling deliver 13°C air at velocity of 2–3,5 m/s. Objective is a well mixed airspace.	Diffusers mounted in the floor deliver 18°C air at about 1,7–3,4 m/s velocity. Air pattern causes some mixing in the occupied space, but a higher temperature near the ceiling.	Diffusers mounted near the floor level deliver 18°C air at less than 0,2 m/s velocity. Air flow causes a thermally stratified space and vertical air movement towards the return.

Supply conditions	Nominally 13°C in cooling.	Typically 15°C–18°C in cooling. Some temperature rise will occur in the underfloor plenum.	Typically 17°C–20°C air in cooling.
Architectural requirements	Space above ceiling for ductwork and ceiling diffusers.	Minimum ceiling height of 2,5–2,8 m recommended. A raised access floor is used as an air plenum and for wiring and communications. Possibility to reduce floor-to-floor height slightly.	Minimum ceiling height of 2,8 m is recommended. Higher ceilings are preferred. Diffusers may take up some wall space. Floor-to-floor height is not necessarily impacted.
Thermal comfort	Even temperatures throughout the space in cooling with proper design. Good thermal comfort with proper air flow. Potential for individual temperature control.	Good thermal comfort with proper airflow. Potential for individual temperature control.	Very good thermal comfort in cooling with proper design. Some potential for drafts near the diffusers.
Ventilation effectiveness	FAIR—Supply air mixes with room air to dilute contaminant . **Effectiveness 50%**	GOOD—Better than overhead distribution, but some mixing occurs in the occupied zone. **Effectiveness 60%**	VERY GOOD—Supply air is delivered directly to occupants, and contaminants are displaced to the upper unoccupied zone. **Effectiveness 60-80%**
Acoustic performance	Diffusers can be a noise source if the air velocity is too high.	Quieter due to low air velocity.	Also quieter due to lower air velocity at the diffusers.
Applications	Any.	Offices or any space with open floor plans.	Schools, restaurants, theaters, atria, and other spaces with high ceilings.

2.6 Components of displacement ventilation systems

Displacement ventilation system has of the same components as a typical supply-exhaust ventilation system. So parts of displacement ventilation are air intake grill, air damper, air filters, (heat recovery, heating and cooling coils) = heat exchanger, fan, silencer, ductwork and diffusers. (Figure 4)

Outdoor air flows through the air intake grille to the ventilation system. Air intake grilles protect the ventilation system flow from rain, snow and foreign objects, like big insects and birds.

The air damper prevents outside air to get into the room when ventilation system is turned off. Air damper is needed in winter time, because without it, the room will get cold air. It is also necessary in the case of fire to avoid fire spreading.

The filter is required for protection ventilation system and ventilated areas from dust and insects. Usually there is installed one coarse filter which traps particles the size more than 10 microns. Additionally, can be installed fine F7 filters. They hold particles to 1 micron.

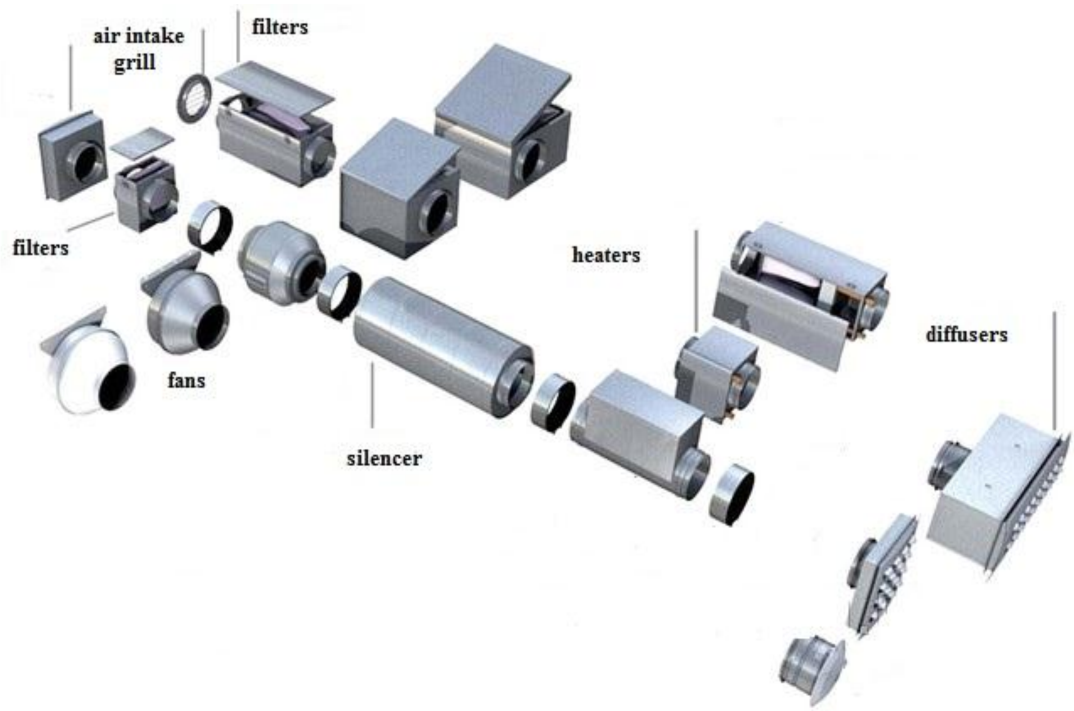

Figure 4.Components of displacement ventilation system /7/

The heater is designed to heat supply air in winter time. Heaters can be water coils (connected to the central heating system) or electrical coils. Sometimes for small supply air units may be cheaper to use electric heaters, but it depends on electricity and heat prices.

The fan is the heart of any ventilation system. It is selected on the basis of two main parameters: volume flow and total pressure. Fans can be axial and radial. Common in Europe are chamber fans. They provide good performance, but are characterized by a low total pressure.

The fan silencer is needed to prevent the spread of noise in ducts. The main source of fan noise is turbulent flows of air inside the system. To reduce this noise is applied sound-absorbing material of a certain thickness. Commonly used absorbent material is mineral wool, synthetic material etc.

After all previous devices, treated air is ready for distribution to spaces. For this purpose is used duct network. It consists of ducts and fittings (tees, bends, reducers).

In case of Mikpoli lecture hall the main differences between ordinary supply-exhaust system and displacement ventilation system are the type of diffusers and miss of duct system directly to the diffusers. Figure 5 shows the Mikpoli chamber. Supply air flows to a big chamber under the seats and air terminal devices are connected to this chamber.

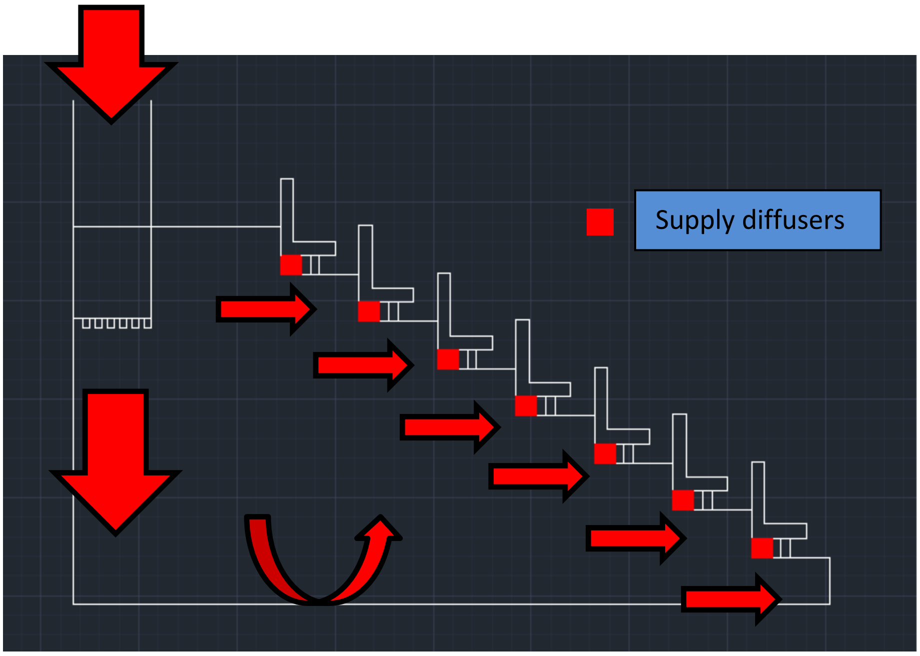

Figure 5.Air distribution of Mikpoli lecture hall. Supply air devices are connected to the chamber locating under the seats.

Very important part of displacement ventilation system and air handling unit is supply diffusers. Diffusers are used for uniform distribution of air flows in the room.

2.6.1 Supply air devices for displacement ventilation systems

Most common draft problems of displacement ventilation are related to high air velocities and too cold supply air temperature in occupied zone. They often are due to the wrong choice of type diffusers. For example, the diffuser which is designed to supply air with big temperature difference (more than 5°C) can be a reason of draft near the floor in conditions of significant changes of temperature. Therefore it is always necessary to choose diffusers designed for each specific case. Also there should be used diffusers only those manufacturers who make their products with the extensive documentation. /2/

The diffusers installation requires space in the wall or on the floor. Therefore, the determining their position requires close collaboration with the architect. Most commonly are used wall diffusers which are installed in a wall or in the corner, free-standing on the floor or carpet. (Figure 6) In addition, the air can be supplied through the floor, in this case it is necessary to take into account the problem that supply air can be polluted cause of dirty floors. /2/

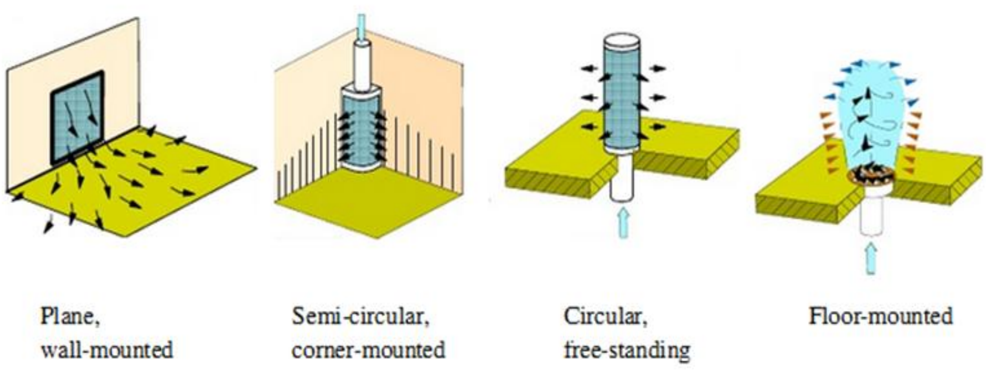

Figure 6.Types of diffusers of displacement ventilation /2, p.3/

Obvious advantage of displacement ventilation diffusers is their adaptability and possibility to change the flow picture of distribution air. Displacement ventilation diffusers should be used in the working area without direct flow with people, which are near the device.

There are low-velocity diffusers equipped with special system, where air nozzles are locating behind a perforated front panel of the diffuser. Turning each nozzle in a certain position, changes the picture of distribution air. /6/ Figure 7 shows this air flow picture of displacement ventilation diffuser.

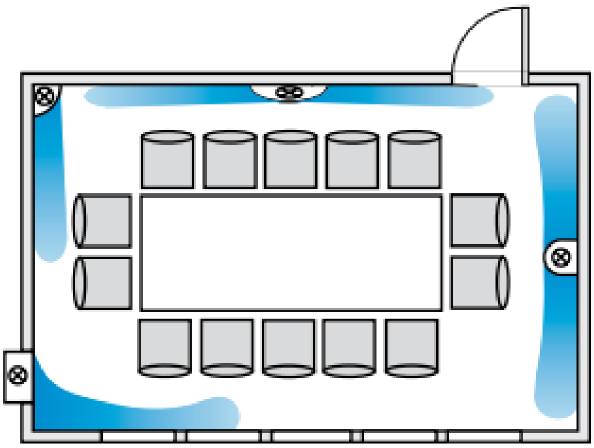

Figure 7.Diffusers with adaptive working area /6,p.5/

Figure 8 demonstrates how displacement ventilation system works without this special system. An unwanted effect on people happens causing draft.

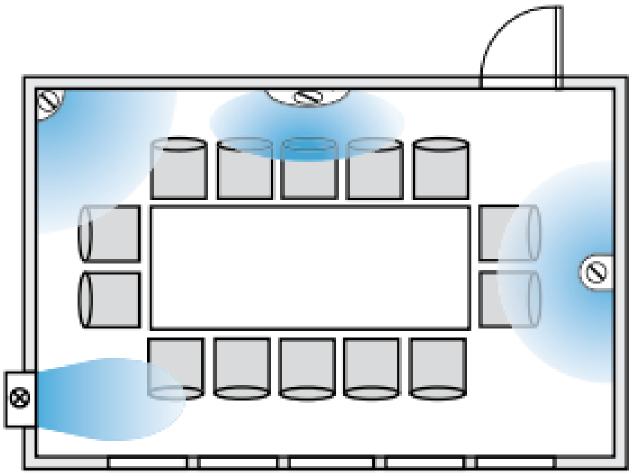

Figure 8.Traditional diffusers with constant working zone /6,p5/

2.7 Classification of displacement ventilation systems

The term «displacement ventilation» is used in literature for various types of air distribution. There are several types of displacement ventilation.

2.7.1 Passive thermal displacement systems

This type of displacement ventilation is most common in Scandinavia and in Finland. In these systems cooled supply air is distributed directly into the work area and removed from the upper zone (Figure 9). Such systems can be called «passive thermal displace systems». Air supply is parallel to the floor, and near the floor is formed a layer of relatively cool, clean air. Heat sources in the work zone create convective flow of heated air upwards, which is a part air of the working area joins to this plume. Thus, warm polluted air accumulates in the upper zone of the room and is removed through extraction equipment located there. Supply air devices with low turbulence suck only a small amount of air and do not contribute to the mixing of the upper and lower zones. Stratification of pollution provides a high air quality in the work area without increasing operating costs. /4/

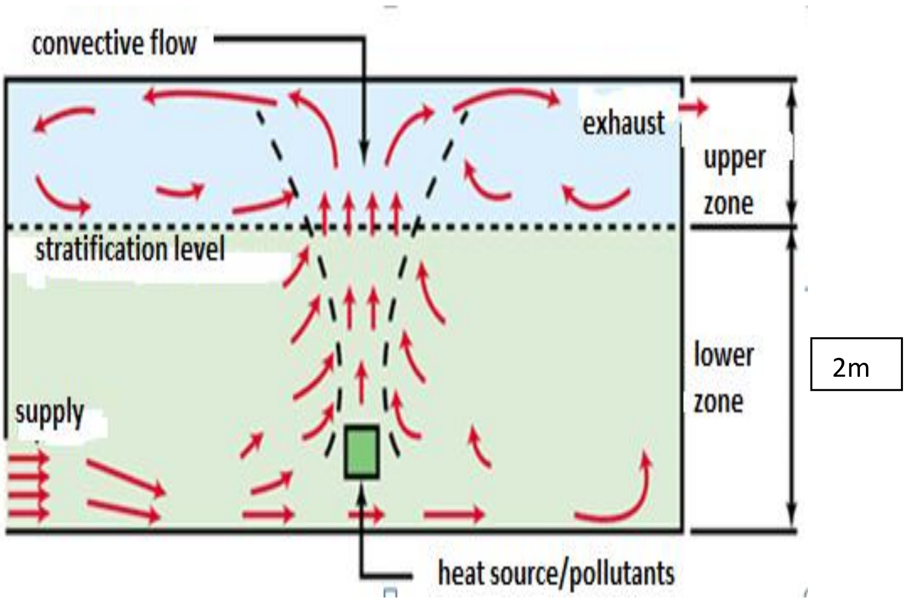

Figure 9.Passive thermal displacement ventilation /4/

Passive thermal displace systems were the first type of displacement ventilation systems. They are widely used in industrial buildings in Scandinavia during for last 30 years. They are still the most common systems of this type in Europe. Recently, the application of these systems has increased due to offices and other commercial buildings where alongside with the quality of air are high demands for comfort. /4/

2.7.2 Systems with unidirectional flow

There are systems which form one-way flow of low turbulence. Supply and removal of air happens with a low velocity through supply and exhaust device with a large surface area, for example, perforated panels. Air flow in such systems, often called "systems with unidirectional flow" or "piston system" can be vertical (air moves through the ceiling and is removed through the floor or vice versa (Figure 10) and horizontal (air moves through one wall, and is removed through the opposite).

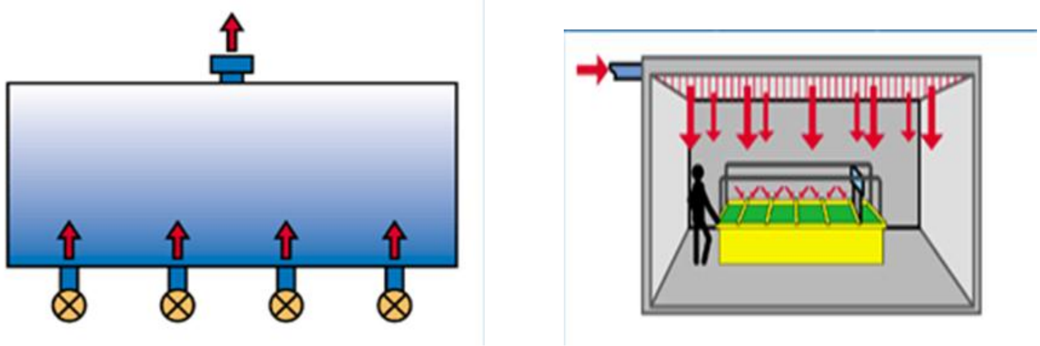

Figure 10.Vertical unidirectional airflow from floor to ceiling and vice versa/4/

In this system supply and exhaust openings are evenly located on the ceiling and the floor or walls. This system creates almost a steady stream of moving air, like a piston through the room. Ventilation systems of this type are used primarily for clean rooms, where the main objective is to remove dirt, or for spaces with large excess heat and / or high concentrations of contaminants. In this case the air change will be high. /4/

2.7.3 Systems with special nozzles

In these systems where the cooled air with low velocities is supplied through diffusers with special nozzles mounted above the work area, and the air is removed from the lower area. Polluted air of the working area is pressed to the floor by overlying flow of fresh air and displaced toward floor exhaust holes (Figure 11). This system allows a stratification of temperature and concentrations of contaminants above the level installation diffusers and prevents penetration of contaminants into the air of the working area. These systems are also sometimes atributed to active thermal displace systems. /4/

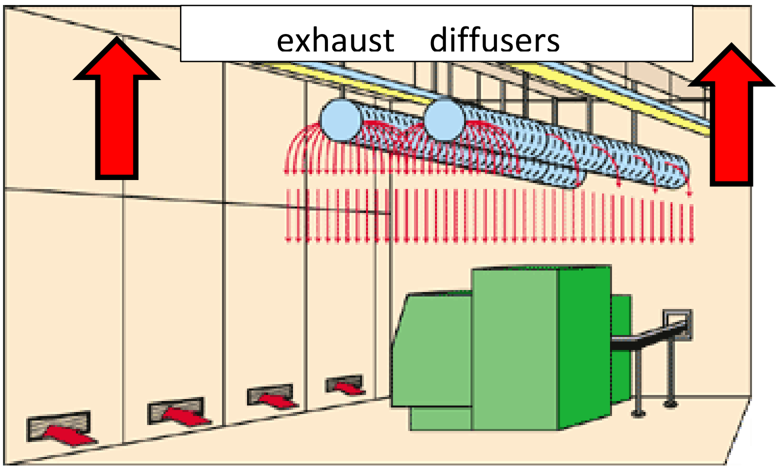

Figure 11.Active thermal displacement ventilation /4/

2.7.4 Systems with the supply air ducts, laid under the floor

In these systems supply air ducts, are installed under the floor (Figure 12). Air distributor devices are locating in the floor, providing a rapid disintegration of supply air stream. Due to internal heat air become warmer, rises and is removed from the upper zone of the room. These systems are installed in rooms where there is a need of fresh air for each person. For example, theaters, lecture halls, conference rooms and etc. Installation of air ducts takes place in special rooms (chambers) located under the seats or supply air devices are connected directly to the chamber as in Mikpoli. /4/

Figure 12.Supply air through floor diffusers with a twisting stream in the auditorium of the University of Amsterdam /4/

2.7.5 Low-impulse systems

Low-impulse systems supply cooling air (Figure 13) from air distributors, locating at ceiling level or at a height of about 3 meters. Cooler air falls toward the work area because it has higher specific density. Then air mix with room air, spreads along floor and go to the lower zone of the room. Room air, heated by internal heat sources, flows and is removed from the upper zone. Some amount of surrounding air mixing to the supply air streams allow to limit the transfer of contaminants in the work area. Such systems are sometimes called "active thermal displacing", because they are more efficient in removing excess heat and pollution than mixing systems. /4/

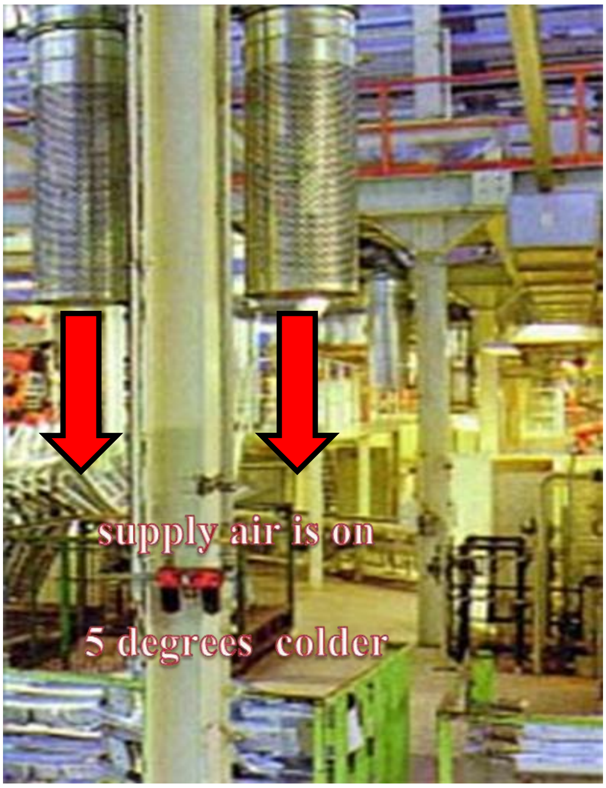

Figure 13.Low-impulse distribution of air through perforated diffusers mounted on columns at a height of 3m in Volkswagen AG plant /4/

3. MEASUREMENTS AND RESULTS

3.1 Initial data

The place of measurements was the Mikpoli lecture hall, M – building of Mikkeli University of Applied Sciences. (Figure 14) This auditorium is very modern. It was built in 2008 and is ready to accept meetings and conferences at the highest level. Its capacity is 120 people. The area of lecture hall is 450 m2. Auditorium has two exits and no windows. On the walls there is installed soundproofing material. Inside Mikpoli lecture hall is used good lighting and acoustics. Type of ventilation is displacement ventilation. The supply air is delivered to the chamber. Supply air terminal units are connected to this chamber.

Figure 14.Mikpoli lecture hall

According to D2 we should have next parameters in a lecture hall

Table 2.Parameters for lecture halls according to D2 /7/

Space type	Outdoor air flow (dm^3/s) per person	Outdoor air flow (dm^3/s)/m^2	Extract air flow (dm^3/s)/m^2	Sound level $L_{A,eq,T}$ / $L_{A,max}$ dB	Air velocity (winter / summer) m/s
Classroom	6	3		**33 / 38 ***	0.20 / 0.30
Corridors / Lobbies		4		38 / 43	
Gym:					
– use for gym purposes		2		38 / 43	0.30
– use as assembly hall		6		33 / 38	0.25
Lecture room	8	6		33 / 38	0.20 / 0.30
Team work area	8	4		33 / 38	0.20 / 0.30
Canteen	6	5		33 / 38	0.25
Storage rooms			0.35		

«The design temperature for the heating season that is normally used for room temperature in the occupied zone is 21°C. The design temperature for the summer season that is normally used for room temperature in the occupied zone is 23°C /7/.»

«The maximum permissible indoor air carbon dioxide content in usual weather conditions and during occupancy is usually 2,160 mg/m (1,200 ppm)» /7/.

I should get air flow per person more than 8 l/s, air velocity of supply air diffusers less than 0,2 m/s, sound level less than 33 DB, temperature about 21°C and CO_2 level less than 1200 ppm according to D2. The information about these values was taken from national building code of Finland.

3.1.2 Supply air diffusers

Different types of displacement ventilation diffusers are used in this lecture hall. 95 mini quarter-circular diffusers (Halton TRC) are installed under the seats. They are special diffusers for auditoriums. (Figure 15) Pressure loss of each diffuser is 20 Pa, when air flow is 12 l/s. Area before contact with the person is 0,2m.

One plane, wall-mounted (Halton AFE) low velocity diffuser is installed near the scene (Figure 16). Area before contact with the person is 3m.

Two semicircular (Halton AFB) diffusers are installed behind the last raw (Figure 17). Area before contact with the person is 1m.

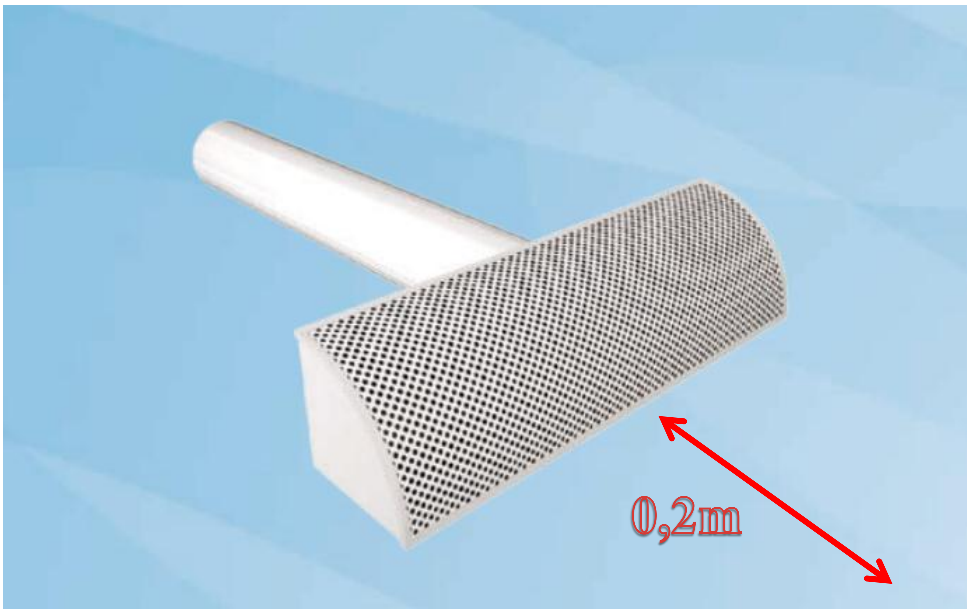

Figure 15.Halton TRC diffuser /9/

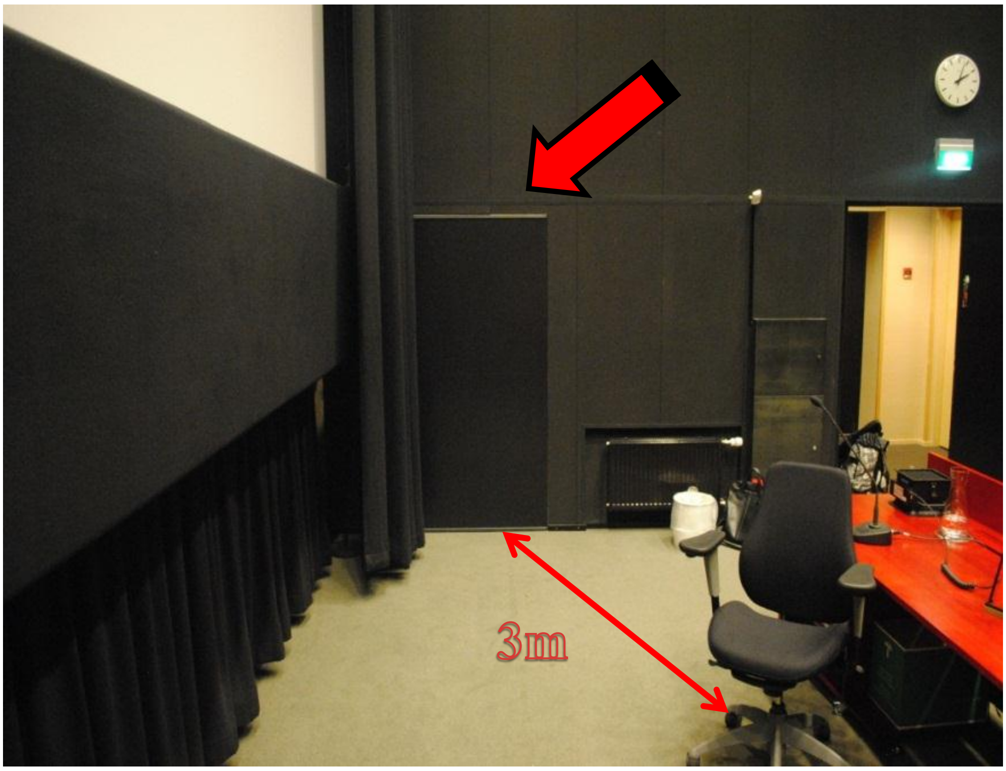

Figure 16. Big plane wall-mounted diffuser Halton AFE near the scene

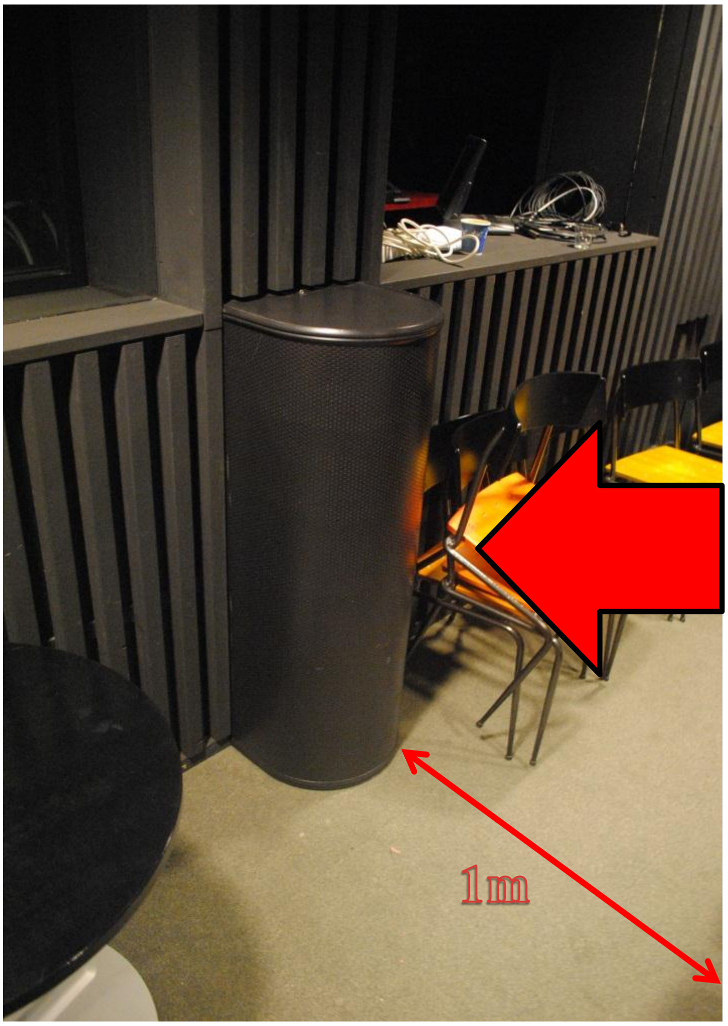

Figure 17.One of two semi-circular, wall-mounted diffusers Halton AFB in Mik-poli

3.2 Measurement devices

3.2.1 Air velocity meter Swema 300

The Swema 300-series has many different instrument models. I used Swema 300 for air velocity measurements. Swema 300 can record 1600 measurements per minute. Accuracy is ± 0,02 m/s. Read value accuracy is ± 3%. (Figure 18) /10/

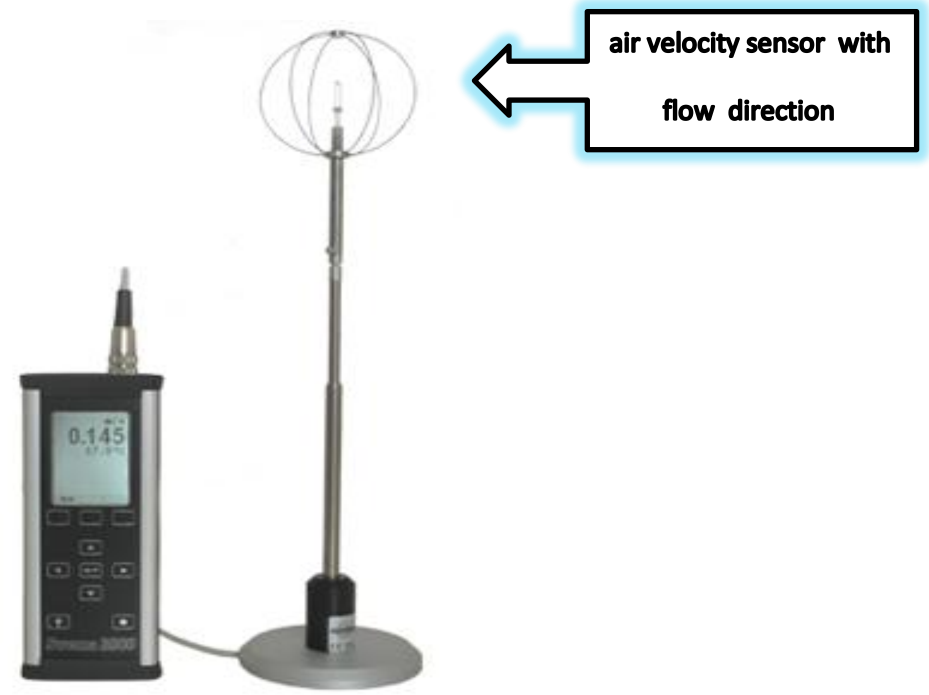

Figure 18.Swema 300 with air velocity sensor /10/

3.2.2 Balometer SwemaFlow 125

Balometer is a volume flow meter. SwemaFlow 125 measures both supply and exhaust air from low from 2 to 125 l/s. Accuracy is 95%. SwemaFlow 125 is basing on the well-known principle Swema, hot-wire network, which provides a good and accurate average flow rate in the capture of the opening. Memory can record 9999 measurements. The data are taken directly on-site from the display. (Figure 19) /10/

Figure 19.SwemaFlow 125 /10/

3.2.3 Data logger EBI-20 T1

This small device measures temperature and humidity in the room. This type of data logger can store 4000 measurements inside. Accuracy: ±0,5 °C Beginning and end of the measurement can be set either manually or automatically. In Mikpoli auditorium the measurements were made using automatically data logger set. The obtained information is handled in the program Winlog. /11/ (Figure 20)

Figure 20.Data logger EBI-20 T1 /11/

3.2.4 CO2 – meter TSI 9565-P

This device measures CO2 concentration in the room. Special handle with sensor allows measure the CO2 concentration in trouble places. The obtained information is handled in special TSI program. Accuracy is ±3%. (Figure 21) /12/

Figure 21.TSI 9565-P /12/

3.2.5 Sound meter Bruel & Kjaer Type 2239A

This device is used for octave band measurements. An LCD display shows the sound pressure levels. It can store more than 40 measurements. (Figure 22) /13/

Figure 23.Bruel & Kjaer 2239A /22/

3.3 Volume flow measurements of supply diffusers

The aim is to deliver the same amount of supply air for each diffuser in lecture hall. So the air flow of each diffuser was measured. When the total volume flow was obtained, it was compared with D2 and Indoor Climate Classification. Volume flow should be more than 11 l/s per person according to S1 class Indoor Climate Classification 2008. Table 3 demonstrates Indoor Climate Classification 2008 values. Total volume flow of diffusers under the seats is 1345 l/s and average volume flow is 12,5 l/s. It means that air volume flow corresponds to S1 class. Table 4 shows volume flow of each mini quarter-circular diffuser under the seats. Design value would be 8 l/s for each person according to D2. The results are quite good. Almost all of diffusers have 12 l/s or more. We can make a conclusion based on average value. Differences between the results are 10% that meets the SFS standard.

Table 3.Air volume flow per person according to Indoor Climate Classification 2008 /8/

	S1	S2	S3
Air volume flow Lecture hall	11 l/s	8 l/s	6 l/s

Table 4.Air volume flows in Mikpoli lecture hall by balometer

Seats/ Rows	1	2	3	4	5	6	7	8	9	10	11	12
1	12.6	12.4	12.2	12.5	12.2	12.2	12.6	12.4	12.9	12.8	12.3	12.3
2	12.5	12.3	12.8	12.8	12.1	12.1	12.4	12.3	12.8	12.2	12.9	12.6
3	12.3	12.8	12.1	12.6	12.3	12.4	12.3	12.1	12.2	12.8	12.1	12.8
4	12.6	12.7	11.8	12.9	12.5	12.2	12.7	12.6	12.8	12.3	12.9	12.4
5	12.2	12.9	12.0	12.2	12.4	12.5	12.3	12.4	12.6	12.2	12.1	12.3
6	12.1	12.7	12.5	12.5	12.3	12.1	12.5	12.8	12.2	12.6	12.6	12.2
7	12.4	12.6	12.4	12.8	12.4	12.3	12.7	12.4	12.4	12.8	12.5	12.5
8	12.5	12.7	12.0	12.4	12.3	12.2	12.6	12.7	12.3	12.1	12.7	12.1
9	12.8	12.8	12.4	12.5	12.2	12.1	12.4	12.4	12.8	12.5	12.1	12.5
Aver. values	12.5	12.7	12.4	12.6	12.3	12. 2	12.5	12.4	12.6	12.5	12.5	12.4
Total volume flow of diffusers under the seats is 1345 l/s, (4845 m3/h) Average volume flow is 12,5 l/s per person												

3.4 Air velocity measurements of supply diffusers

The aim of air velocity measurements is to check possible draft caused by the supply diffusers of ventilation system. One of the most important parameter of displacement ventilation is low velocities. Air velocity should be less than 0,14 m/s according to Indoor Climate Classification 2008. It means that velocity value corresponds to S1 class inside lecture hall. Table 6 shows air velocity values according to Indoor Climate Classification 2008. According to D2 it should be less than 0,2 m/s. First of all, it was interesting to see the velocities under the seats, because if results will be too high probability of shin cooling greatly increases. (Figure 23) The distance between diffuser and legs of person is about 0,2 m. So the adjacent zone is very small. I measured velocity on distance 0,2m. Table 5 shows obtained results. They were predictable. All results are less than 0,1 m/s. Average temperature of supply air is 18,6°C. It is 3°C less than ambient air temperature on It is the first proof that the type of ventilation inside is displacement ventilation. It means that the rule of displacement ventilation works. The results are shown in the Table 5. Velocity in winter time should be less 0,2 m/s according to D2. Velocity is not constant, there are small fluctuations but they are insignificant. People inside Mikpoli lecture hall can feel themselves comfortable and enjoy fresh air with low velocity. When supply air temperature is 18,4°C and air velocity is 0,07 m/s, it means that Predicted Mean Vote is neutral and Percentage Person of Dissatisfied is 5%.

Table 5.Air velocities of supply diffusers under the seats in Mikpoli lecture hall

Seats/ Rows	1	2	3	4	5	6	7	8	9	10	11	12
1	0.04	0.06	0.05	0.04	0.06	0.04	0.06	0.02	0.02	0.02	0.02	0.02
2	0.05	0.03	0.06	0.03	0.04	0.05	0.05	0.04	0.04	0.04	0.03	0.03
3	0.06	0.04	0.04	0.04	0.05	0.04	0.04	0.03	0.03	0.02	0.04	0.02
4	0.07	0.05	0.04	0.06	0.05	0.03	0.05	0.02	0.03	0.03	0.01	0.03
5	0.05	0.06	0.05	0.05	0.03	0.03	0.04	0.03	0.02	0.03	0.02	0.02
6	0.06	0.05	0.05	0.03	0.05	0.03	0.05	0.03	0.03	0.02	0.03	0.02
7	0.06	0.04	0.06	0.05	0.05	0.02	0.04	0.04	0.03	0.03	0.04	0.02
8	0.08	0.05	0.05	0.06	0.03	0.05	0.04	0.02	0.03	0.03	0.03	0.03
9	0.04	0.05	0.06	0.05	0.06	0.07	0.05	0.02	0.02	0.02	0.02	0.02

Average temperature in lecture hall during the measurement was 18,4°C

Table 6.Air velocity according to Indoor Climate Classification 2008 /8/

	S1	S2	S3
Air velocity(winter)	0,14 m/s	0,17 m/s	0,2 m/s

Figure 23.Air velocity measurement of supply diffuser

Air velocities of Halton AFB wall-mounted, semi-circular diffusers were 0,04 m/s and 0,03 m/s, measured from a distance of 1 m. In this case human body zone of possible draught is neck. Velocity measurements are very important because neck is the most sensible part of human body. Air velocity of Halton AFE plane diffuser was 0,02 m/s. The measured distance was 1,50 m. According to my measurements air velocities are low and correspond to the standards.

3.5 Relative humidity and temperature measurements

In order to understand how good displacement ventilation works in the lecture hall, it was measured temperature and humidity inside. Values were measured to check another displacement ventilation rule. Temperature inside must increase as it approach to the ceiling. These parameters were measured in 3 different points, because of great sizes of lecture hall. Figure 24 and 25 demonstrate the locations inside. During measurements were 46 persons inside, almost a half from whole capacity. Duration was 2 hours. That is enough to give temperature fluctuations on 3-4℃ . Figures 26, 27 and

28 show the information in each point. Maximum temperature deviation in all 3 points is 0,4℃. Maximum relative humidity deviation in all 3 points is 2,6%. These deviations are insignificant and it means that ventilation works on good level. People who are in this auditorium should feel themselves comfortable. Average temperature in logger 1 is 20,5°C. Average temperature in logger 2 is 21,3°C. And the last one is 22,2°C. It means that temperature rises inside lecture hall. (Figure 30) It is the second proof that the ventilation type is working as displacement ventilation. Temperature inside should be approximately 21°C. /1/ Average relative humidity is 43%. According to outdoor air x-value is 39%. It means that 4% are produced by people inside. Relative humidity should be more than 25% according to S1 class Indoor Climate Classification 2008. It means that relative humidity value corresponds to S1 class.

Figure 24.Locations of data logger 1

Figure 25.Locations of data loggers 2 and 3

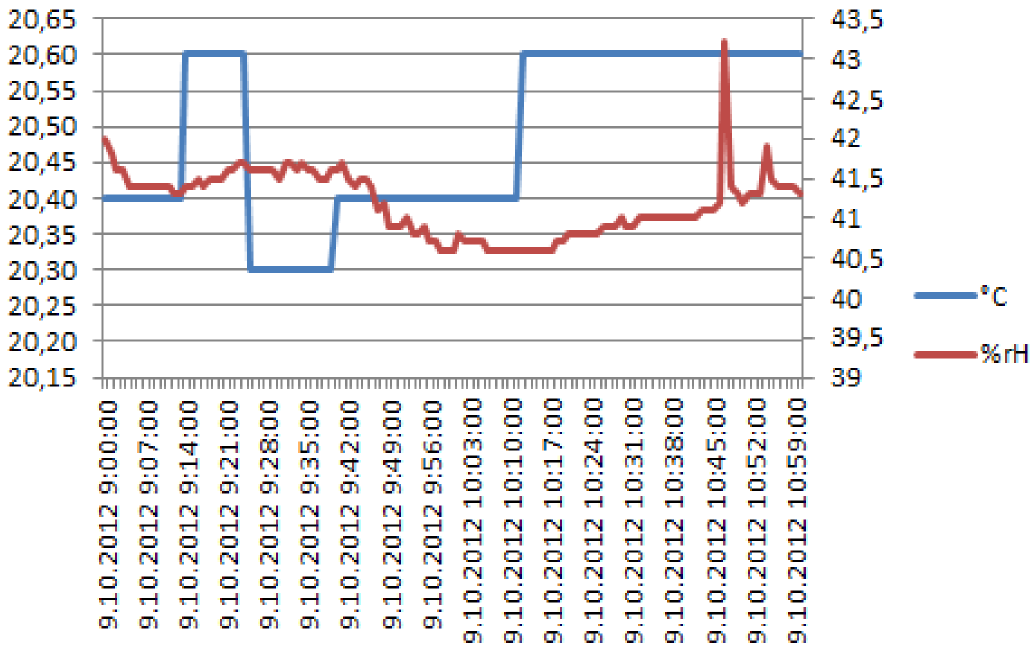

Figure 26.Temperature and relative humidity from Data logger 1

Average temperature is 20,5°C. Average relative humidity is 41,7%

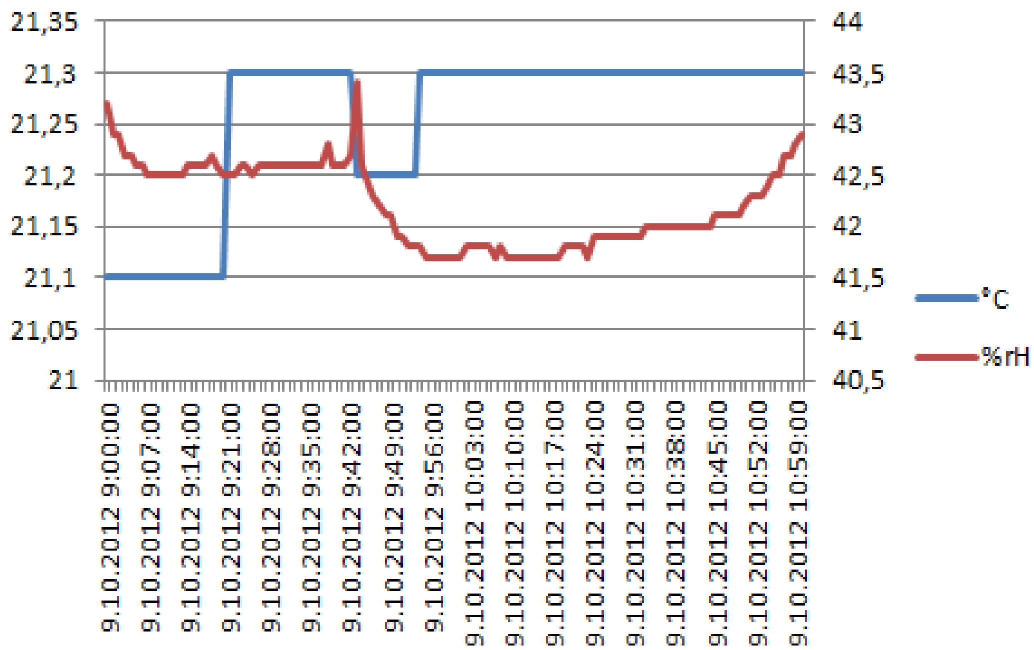

Figure 27.Temperature and relative humidity from Data logger 2

Average temperature is 21,3°C. Average relative humidity is 42,5%

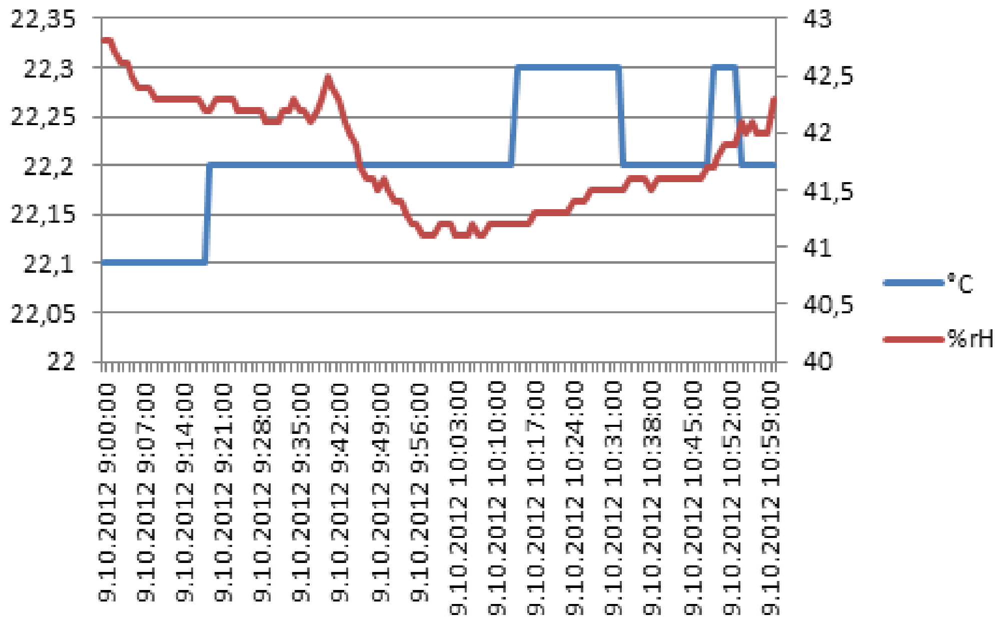

Figure 28.Temperature and relative humidity from Data logger 3

Average temperature is 22,2°C. Average relative humidity is 42,0%. Supply air temperature is 18,4°C. Vertical temperature gradient should be not more than 2 °C according to Indoor Climate Classification 2008. Vertical temperature gradient is 1,8°C. It means that temperature gradient value corresponds to S1 class. Table 7 shows temperature gradient value according to Indoor Climate Classification 2008.

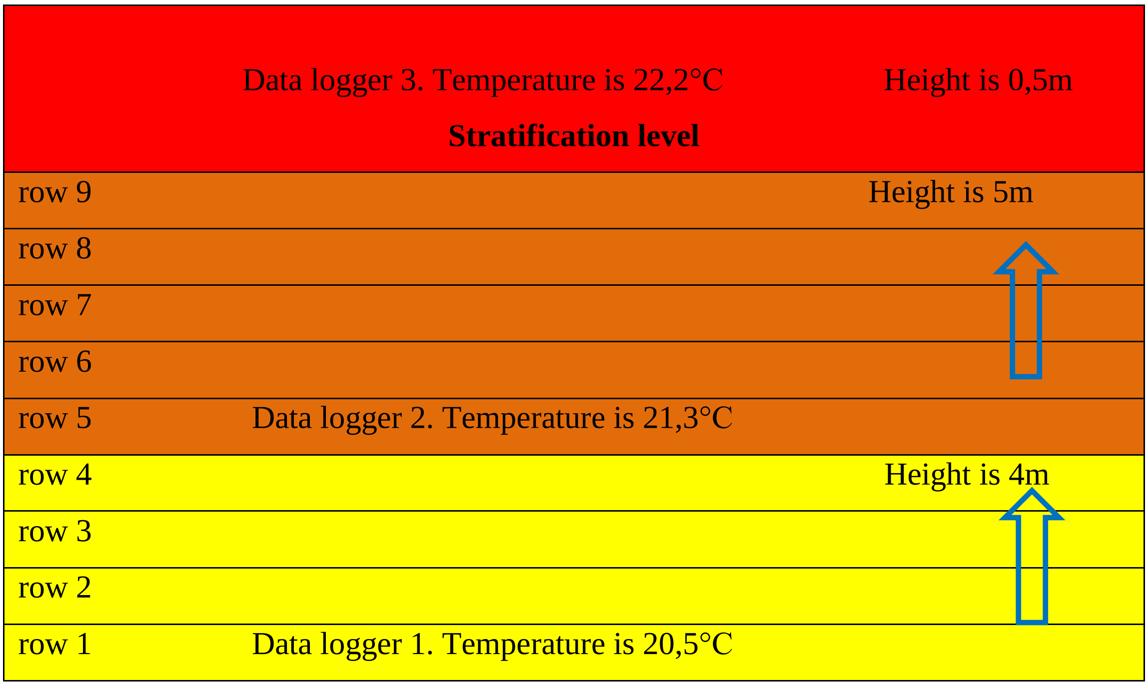

Figure 29.Rise of temperature in lecture hall

Table 7.Vertical temperature gradient according to Indoor Climate Classification 2008 /8/

	S1	S2	S3
Vertical t° gradient	2 °C	3 °C	4 °C

3.6 CO_2 and noise measurements

CO_2 is a very important parameter of indoor climate. According to D2 the critical value is 1200 ppm. Table 8 shows CO_2 values according to Indoor Climate Classification 2008. It means that S3 class corresponds to D2 value.

Table 8.CO2 level according to Indoor Climate Classification 2008 /8/

	S1	S2	S3
CO_2 concentration	< 750 ppm	< 900 ppm	< 1200 ppm

Figure 30 shows the results when inside lecture hall were 46 persons. CO_2 – meter was installed on the fifth row in the center of lecture hall. Measurement height was 2,5 m above the floor. The maximum CO_2 level is 712 ppm and the minimum value is 635 ppm. It means that CO_2 level corresponds to S1 class according to Indoor Climate Classification 2008. When the auditorium is free average result is 400-420 ppm. It means that the CO_2 level equals to outdoor air.

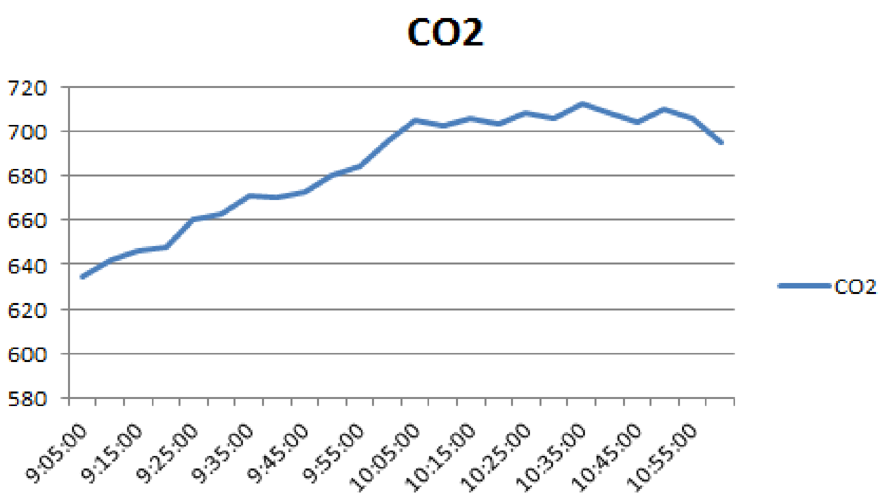

Figure 30.CO_2 level in lecture hall.

Noise level near supply diffusers is 23DB. Permissible value is 30 DB according to Indoor Climate Classification 2008. Table 9 shows permissible noise value according to Indoor Climate Classification 2008. Mikpoli lecture hall corresponds to S1 class according to Indoor Climate Classification 2008. It means that displacement ventilation system works quietly, without any noises.

Table 9.Noise level according to Indoor Climate Classification 2008 /8/

	S1	**S2**	**S3**
Noise level for educational buildings	**< 30 DB**	**< 35 DB**	**< 35 DB**

4. CONCLUSION

In conclusion I would like to say that according to my measurements displacement ventilation is a very good system in such places as lecture halls. Displacement ventilation is used more and more in educational facilities and in another spaces with high ceilings and high heat loads.

Displacement ventilation has done its job perfectly according to my measurements. All obtained results corresponds not only D2, but Indoor Climate Classification 2008. One minus is that people inside cannot regulate and control air flow. Except of this all measured values corresponds to S1 class. It is the highest in this Finnish classification. First of all, temperature and relative humidity has comfortable values for this large area. Temperature rises from floor to ceiling. It means that there is a vertical temperature gradient inside the lecture hall. It does not exceed 2°C. Secondly, each person gets enough fresh air. Thirdly, people will not feel drafts under their seats because all velocities are very low and supply temperature is not too cold. The maximum air velocity from supply diffuser is 0,07 m/s. They should be less than 0,2 m/s. Fourthly, CO_2 level is under S1 level. Finally, the system runs smoothly and silently. No one will be disturbed by noises coming from the ventilation system. The maximum value cause by all supply diffusers is 23 DB. The measurements were used the advanced tools of different Scandinavian manufacturers. people who are inside during the lectures can get a real pleasure from the indoor climate. According to PPD 95% of people will feel very comfortable and cozy.

The measurements have shown that the ventilation inside Mikpoli lecture hall is working as displacement ventilation. Two basics conditions were performed. First is that supply air temperature of the diffusers is a little bit lower than the ambient air temperature. The second is that temperature rises from floor to ceiling. So there is vertical temperature gradient inside.

Compared with mixing ventilation, I can conclude that displacement ventilation has some very important advantages. Firstly, high air quality is provided inside occupied zone. Secondly, low mobility of air is in the entire work area. Finally, displacement ventilation provides high effectiveness ventilation coefficient, approximately about 70%.

Bibliography

1. Svensson, A.G.L. Nordic Experiences of Displacement Ventilation Systems ASHRAE Transactions. 1989.

2. Elisabeth Mundt, Peter V. Nielsen. Displacement ventilation in non-industrial premises. Hakon Skistad. 2001.

3. Price – HVAC. Displacement ventilation in schools. WWW document. http://www.price-hvac.com Last updated 2011. Referred 6.08.2012.

4. A.M. Givov, Peter V. Nielsen. Displacement ventilation systems in industrial buildings. АВОК №5. 2001.

5. Energy design resources. Displacement ventilation. Design brief. WWW document. http://www.energydesignresources.com. Last updated 08.2005 Referred 29.10.2012.

6. Swegon diffusers. Catalogue. 2011.

7. D2. National building code of Finland.

8. LVI 05-10440 en. Indoor Climate Classification. 2008.

9. Diffusers and terminal units. WWW document. http://halton.com. Last updated 2012. Referred 7.11.2012.

10. Swema. Air flow instruments. WWW document. http://www.swema.com. Last updated 2012. Referred 7.11.2012.

11. Ebro. Ebro industry production. WWW document. http://www.ebro.com. Last updated 2012. Referred 2.11.2012.

12. TSI. TSI indoor climate products. WWW document. http://www.tsi.com. Last updated 2012. Referred 7.11.2012.

13. Bruel&Kjaer. Hand-held instruments. WWW document. http:/www.bksv.com. Last updated 2012. Referred 5.11.2012.