# Optimisation of Personal Ventilation in Aircrafts

by

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# ABSTRACT

The key case in the report is working on optimization of personal ventilation in aircrafts.

First part of research is dedicated to improving shapes and dimensions of textile ventilating surfaces. Seat strap and seat cover are investigated. As a conclusion prototype of angled seat cover is invented.

Second part covers measurements in cabin section model. New systems, combined with Personal Ventilation, are taken into consideration. Results for Mixing Ventilation with PV and Displacement Ventilation with PV are shown in Tables and Figures. In addition, effectiveness's, ventilation index and air quality index, as an important factor in protecting passengers from cross infections, are presented for particular models.

All the experiments base on breathing thermal manikins usage. The measurements results for velocity, temperature and tracer gas concentration, as a contamination, are included.

Simulations done in Computational Fluid Dynamics program, called FloVent are conducted, provide additional information about air movements, temperatures and contaminants distributions.

*Master Thesis, 10th semester*
*Indoor Environmental Engineering*
*Department of Building Technology*
*And Structural Engineering*
*Aalborg University*
*Aalborg*

# PREFACE

This report is the documentation for the 10th semester project "Optimisation of Personal Ventilation in Aircrafts" which was done on the Indoor Environmental Engineering Master's Program at the Department of Building Technology and Structural Engineering, Aalborg University from February 2008 till June 2008 with Prof. Peter V. Nielsen as a supervisor.

Our chance to attend 9th and 10th semester at Aalborg University was enabled by the Long life Learning Program (LLP) in cooperation between Aalborg University and Technical Universities of Gdansk and Warsaw.

Supervisors from the polish side were dr inż. Arkadiusz Ostojski from Gdansk University of Technology, Department of Civil and Environmental Engineering and prof. dr hab. inż. Bogdan Mizieliński from Warsaw University of Technology, Department of Environmental Engineering.

Especially we would like to express our gratitude to our supervisor Prof. Peter V. Nielsen for helping us with never ending problems, giving us valuable information and leading us during our research. Thanks to his dedication and engagement, we were able to do finalize our project.

Also we would like to show our appreciation to our supervisors in Poland, prof. dr hab. inż. Bogdan Mizieliński and dr inż. Arkadiusz Ostojski for always keeping an open door, and being ready to help us with any suggestions.

We would like to thank Rasmus Lund Jensen, for preparing laboratory equipment as well as models, and Torben Christensen for his valuable assistance during the project. Torben was always ready to solve all our technical problems with a smile on his face.

Bente Jul Kjærgaard was a person who deserves our thanks for every help and great patience in dealing with our endless problems and never ending questions.

Many thanks for KE Fibertec AS Company, for good cooperation and preparing textile diffusers.

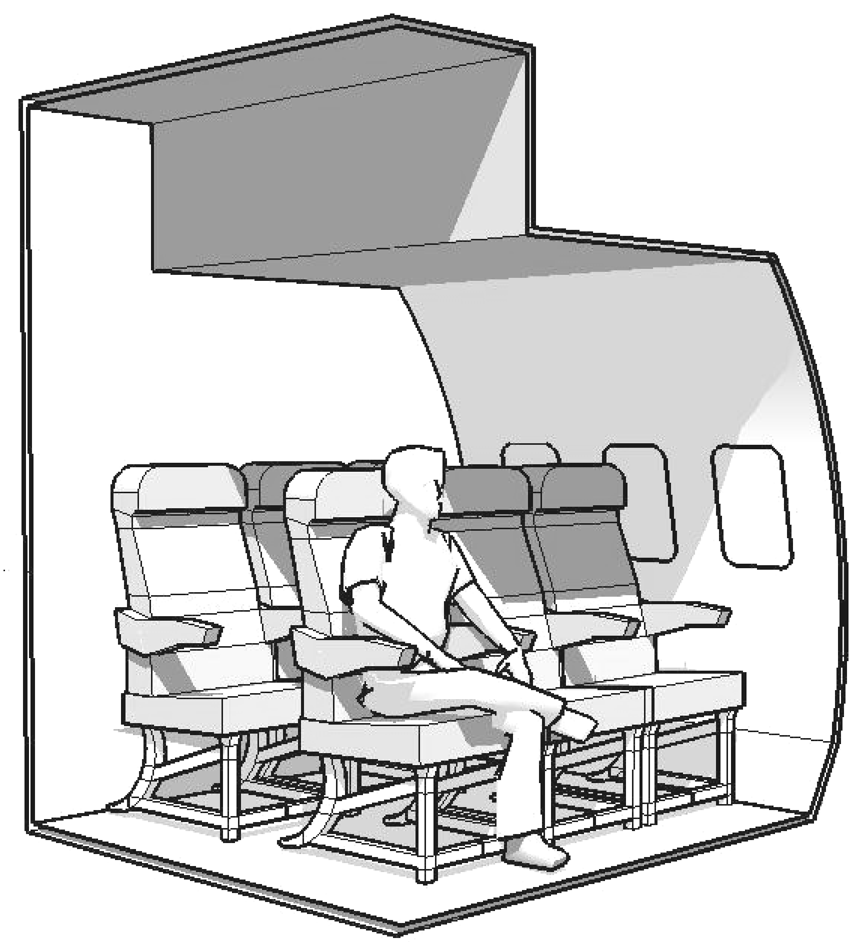
Finally, we would like to thank our families and friends for support.

Tomasz Czarnota     Michał Jasieński

# *Contents*

# 1.CHAPTER

# INTRODUCTION



"*More you know, more is to invent*"
*Francis Scott Fitzgerald, 'The Last Tycoon'*

The following project was created by two Polish students as a Master Project at The Department of Building Technology and Structural Engineering at Aalborg University from February 2008 till July 2008. It is a strict continuation of a $9^{th}$ semester thesis from 2007, which Tomasz and Michał were part of authors as well. The project is focused on a research of optimisation of shape and type of textile ventilating surface as a diffuser, which is can be considered as a new approach to personalized ventilation (PV) in aircrafts.

Problem of contamination in breathing air in crowded and closed rooms were clearly introduced in $9^{th}$ semester report: "New Solution for Personal Ventilations in Aircraft. Textile Ventilating Surface"

Nowadays life style makes people spend most of their time in indoor environments during their work, normal life or entertainment. Often happens that they stay together with other people who may be also a source of many contaminants, diseases and viruses in the same time. That is why it is very important to supply buildings with a high quality of air (suitable temperature, velocity and humidity). However, it is very difficult to find proper parameters of air because they depend on peoples' needs and the type of work they do, performed activity, clothing insulation, etc. Also personal needs are different, for example, according to individual metabolism which affects human demand for external heat. Also working environment is an important factor, especially polluted area which requires special ventilation system. In practice it is very difficult to adjust the centralized ventilation to everyone's requirements. One way of solving this problem is personalized ventilation, which is becoming more and more popular. [1]

System which has been proven to be a very efficient in protecting human beings from cross infection is known as a Personal Ventilation. Clean air is supplied directly to the breathing zone. This may be performed by a set of nozzles above the person's head, a panel near a working station (for example Computer Monitor Panel-CMP), a desk grill, etc (supply Air Terminal Devices). This system can be used in aircraft cabins as well as in trains, buses or offices. In this project special seat cover diffuser for aircraft seats (which is in natural contact with skin) was investigated.

Nowadays, diseases which are transported with air are very common . The air inhaled by people may be contaminated by several ways, such as chemicals, odours or contagious diseases (mainly those airborne). Crowded areas, like aircrafts, busses, trains, are perfect environment for spreading those kinds of contaminations. Problem increases when the ventilation air is partly recirculated, what is common for planes' ventilation systems. "Older model airplanes (…), provide 100% fresh air to the aircraft cabin. Newer models (…) provide up to 50% re-circulated air" [2]. When an infected person sneezes, coughs or talks, releases germ-laden droplets in the same time. They evaporate rapidly in the surrounding environment, and are transported with drought. Even though, recycled air has to go through filtration system, the close quarters of the aircraft cabin environment could facilitate disease transmission [2].

This problem was seriously proved in 2003, while eighteen passengers were infected with SARS (Severe Acute Respiratory Syndrome) on a flight from Hong Kong to Beijing. This syndrome was originated in November 2002 in rural Guangdong Province in China [3] and then was exported via Hong Kong ('gate' between Asian and European market) to the rest of the world [4]. Largely because of infected persons travelling by aircraft.
The influence of those days is still visible on boarders of Hong Kong district. Health – care campaign, face mask and intensive caution are very common.
Not only SARS could be transmitted and spread with air flow, but measles, tuberculosis (TB), chicken pox, anthrax, influenza, smallpox as well.

Apart from all the advantages of PV, this system has one serious problem, which makes it difficult to apply in many cases- it requires person to be basically without any motion. [5]

In this report we are trying to optimise a new approach to personal ventilation – ventilating textile surfaces. In first part of our research we focus on seat strap, seat cover diffuser as well as new angle seat cover, equipped with nozzles connecting it to the fresh air supply.

During our measurements we are trying to find out the relations between shape of diffuser, draught in a cabin and flow from PV to obtain the best effectiveness

Laboratory is equipped, similarly to 9th semester project, with a full scale model of aircraft cabin and seat which is in use in Boeing 737. Thermal manikin with a breathing function is simulating human being. To obtain results we are mixing supply air with tracer gas to check gas concentration in air inhaled by passengers. Working on a second model, which is 1:1 scale model of Boeing 737-200, we are trying to measure Personal Ventilation combine with Mixing and Displacement Ventilation. MV is a system that is used in aircrafts nowadays, but using DV to supply passengers with fresh air is innovative idea. Results in protecting human from cross infections for these two models and alone MV and DV are presented in further chapters.

The main part of the report bases on tracer gas concentration measurements.

We are using smoke simulation to observe air flow in all combination of ventilation systems. It lets us verify tracer gas measurements, as well as gave us clear view of air movement in aircraft cabin.

CFD simulations are conducted in digital model of cabin section. They deal mainly with contaminants distribution, temperature and velocity of indoor air. Those simulations are considered as a separate source of information, and results are compared with results from laboratory measurements.

We do believe that our project and measurements we are conducting would be good basement for further research in filed of problems with airborne infection.

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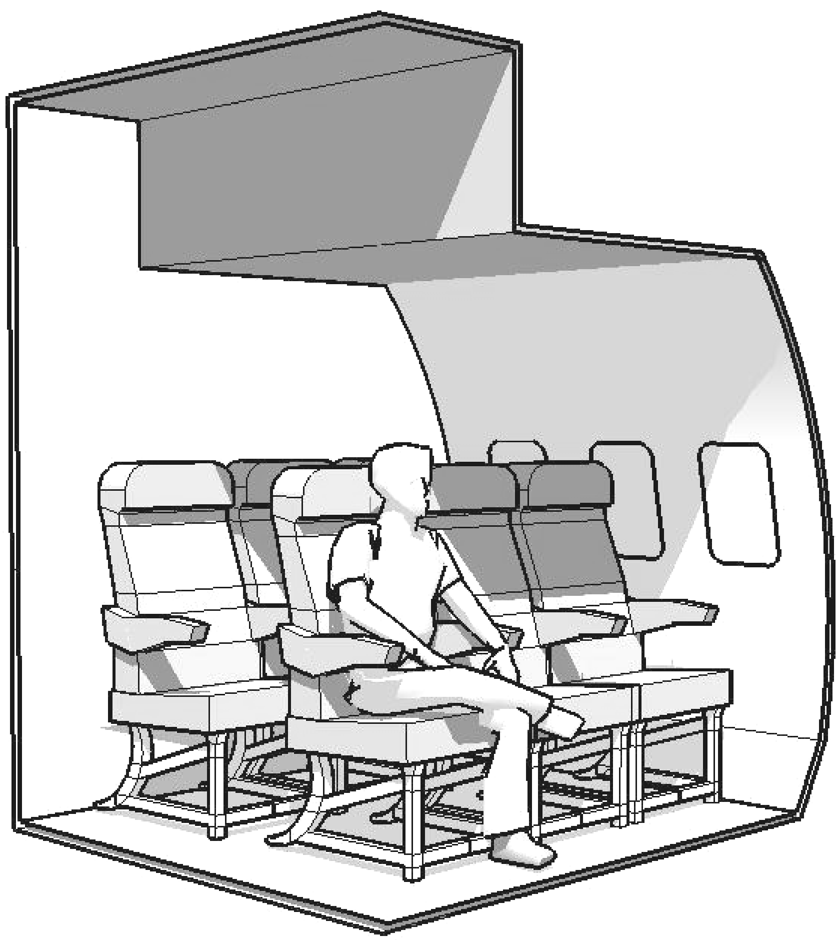
# 2.CHAPTER

# LAST SEMESTER PROJECT



## 2.1. Reference to the last semester project

This report is a continuation of a 9th semester project held at Aalborg University from September 2007 till January 2007: "New Solution for Personalized Ventilation in Aircrafts. Textile Ventilating Surfaces".

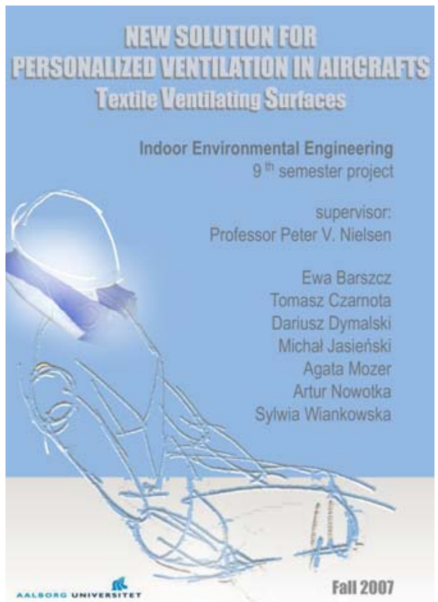



*Figure 2.1. Cover of 9th semester project report.*

The purpose of that project was to investigate the personal ventilation system applied in the aircraft seat. The measurements were held in the wind channel with the airflow of 0.05, 0.10, 0.15, 0.20 m/s generated by the fan.

The Breathing Thermal Manikin "Comfortina", representing human being, was placed in the wind channel and was equipped with the personal surface diffuser (head rest). The measurements were carried out for manikin with and without breathing function.

The experiments conducted last semester were mainly focused on tracer gas concentration measurements. Tracer gas supplied to the textile surface diffuser was used to calculate the protection that this surface provides.

The effectiveness of the head rest was checked in three positions of the aircraft chair. Firstly, manikin faced directly the draft in the wind channel (0° position). Second position was for the chair rotated of 90°. The last one was for the chair rotated of 180°, which represented the draught coming toward the manikin's back.

*Figure 2.2. Head rest*

Beside those measurements, thermal comfort of manikin exposed to the personalized ventilation system was also checked by calculating the Equivalent Homogenous Temperature (EHT).

To visualize how the neck supporter diffuser worked and what were the flow patterns of the air coming out of the head rest, smoke simulations were made.

The data gathered during the experiments provided wide knowledge about relations between effectiveness and a drought in a wind channel, flow rate in PV and position of a manikin.

## 2.2. The results from the last year project

Here are presented measurements results for the head rest diffuser put in a position when the best effectiveness were obtained. It was the first set up, where the neck supporter was wrapped around the neck of the resting person.

Results for position of 90° were very satisfying because high effectiveness is reached for big range of airflow rates in the neck supporter diffuser starting from 8 l/s (see Figure 2.3.). Fresh air from one side of the head rest was always blown to the direction of passenger's breathing zone. The maximum amount of air that people traveling by aircrafts are supplied with is 10 l/s. In this situation it would be possible to decrease this value.

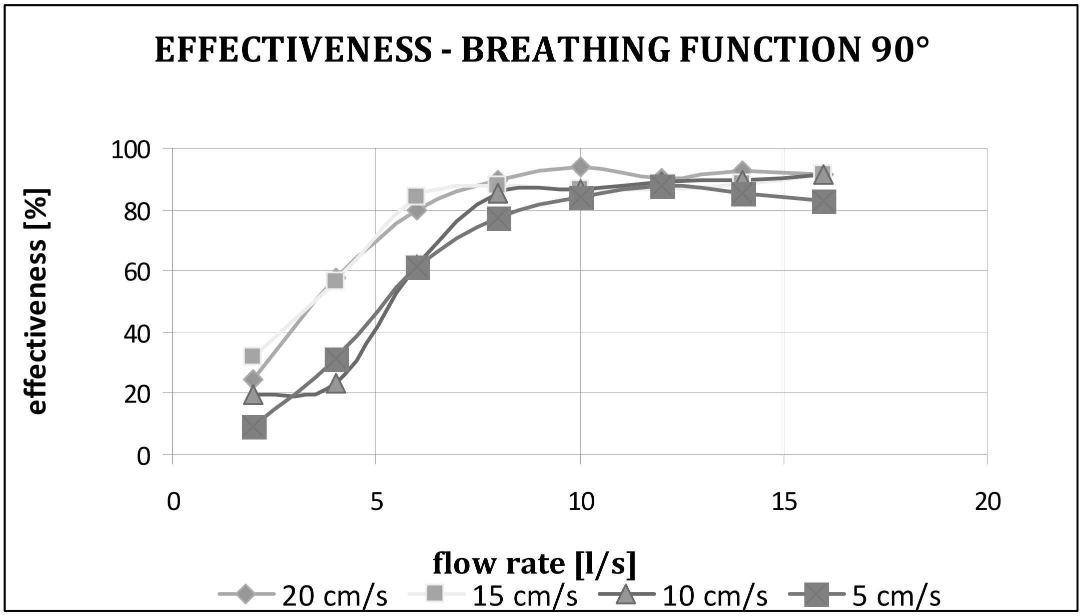



*Figure 2.3. Effectiveness – with breathing function; position 90°*

Also position 180° were very satisfying (see Figure 2.4.). This seat location was connected with person's thermal comfort. Surrounding air was blowing to the back of the chair so that passenger was protected from the draught caused by mixing ventilation. No matter how high the velocity in the place was people wouldn't fell a big difference.
Good results were obtained for airflow rate values starting up from only 10 l/s.

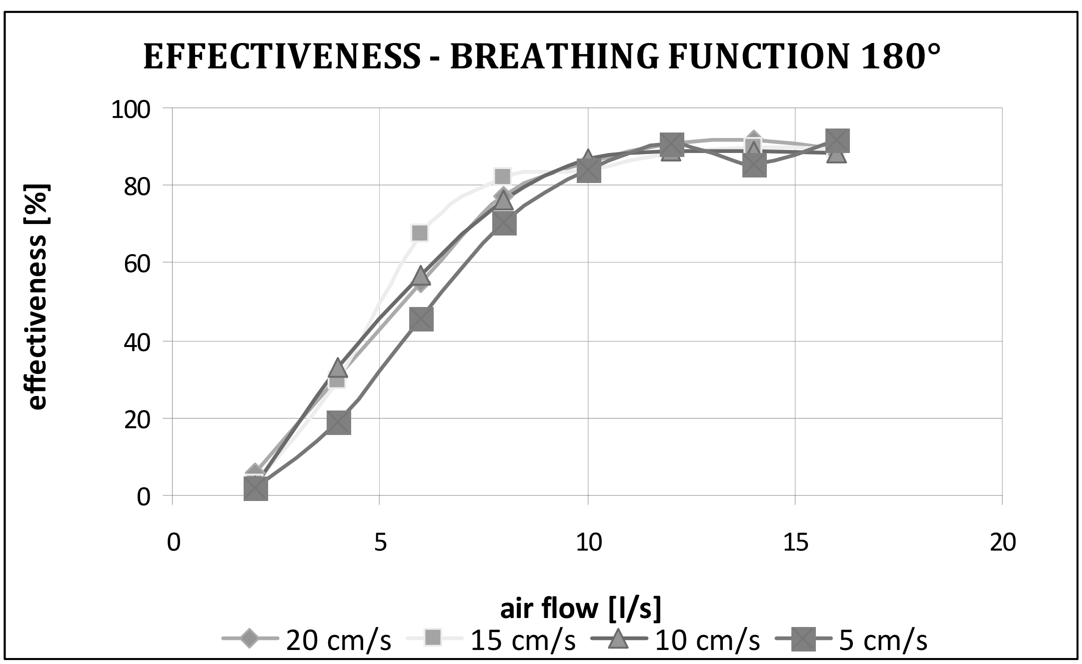



*Figure 2.4. Effectiveness – with breathing function; position 180°*

Thanks to those researches, neck supporter diffuser could be considered as a sufficient way of protecting people from various air contaminants and cross infections. Achieved effectiveness, up to 94%, is very satisfying.

But the second conclusion was that it could be possible to get even better effects after further head rest construction improvement. The thing that would make the diffuser more attractive was the possibility of creating self-adjustable system. In general it is very hard to satisfy everybody with the air conditions in a room thanks to fact that each person has different sense of thermal comfort. Furthermore, development of the neck supporter appearance should be taken into consideration to create more comfortable and user friendly construction.

This brings to the conclusion that personal ventilation textile surface is an interesting field for further investigation. So that a new and extended research were carried out to broaden knowledge in personal ventilation purpose. This project focuses on optimizing personal ventilation in mass means of transport, such as aircrafts.

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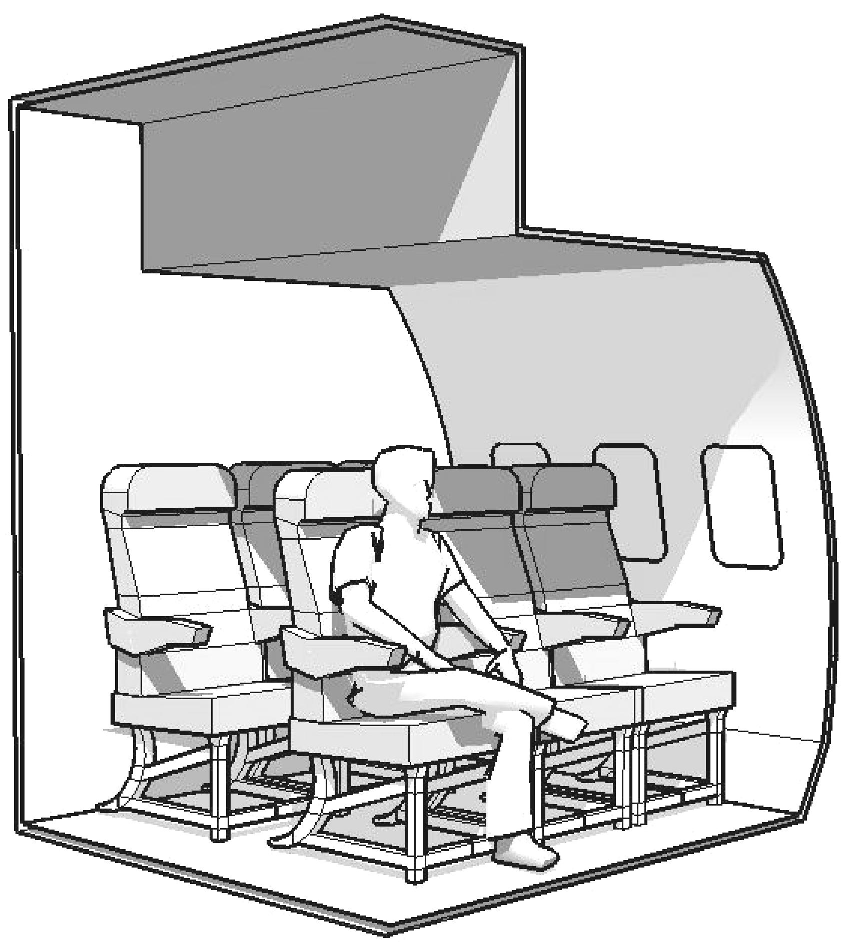
- E. Barszcz, T. Czarnota, D. Dymalski, M. Jasieński, A. Mozer, A. Nowotka, S. Wiankowska, “New solution for Personalized Ventilation in Aircrafts. Ventilating textile Surfaces” Aalborg University 2007,

# 3.CHAPTER

# IDEAS



Nowadays, mixing ventilation in aircraft is supported with nozzles above the passenger's head as a personal ventilation system. However, this solution causes some inconvenience (see Chapter 4.1.6.)

To avoid those kinds of problems we are trying to investigate the use of textile personal diffuser integrated with aircraft seat. Last semester project shows that PV improves condition in aircrafts. In this project we focus on finding the best shape and optimizing type of textile personal diffusers. These experiments are conducted in wind tunnel model.

Air supplied inside aircraft should have a low velocity level to provide satisfying thermal comfort, but on the other hand, should have a big air flow to reach all passengers' breathing zones. Using cabin section model, we are trying to find solution between those needs and protection again cross infection as well.

Two variants of basic air flow are taken into consideration – mixing and displacement ventilation. By measuring different air flows we are trying to find the best rate for protecting from passengers from diseases (see Figure 3.1. and 3.2.).

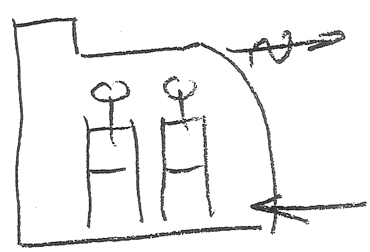


*Figure 3.1. Idea of Mixing Ventilation in cabin section model (sketch by prof. Peter V. Nielsen)*

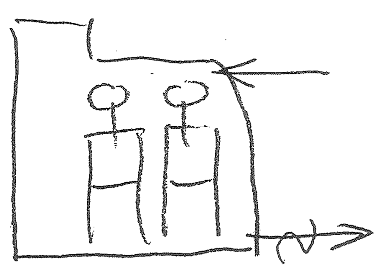


*Figure 3.2. Idea of Displacement Ventilation in cabin section model (sketch by prof. Peter V. Nielsen)*

Other idea, beside those two systems themselves, is to combine them with personal ventilation. By adjusting different flow to personal ventilation diffusers, we are trying to find the best relation between airflow from PV and mixing or displacement ventilation. Figures 3.3 and 3.4. shows the ideas of different combination of those systems.

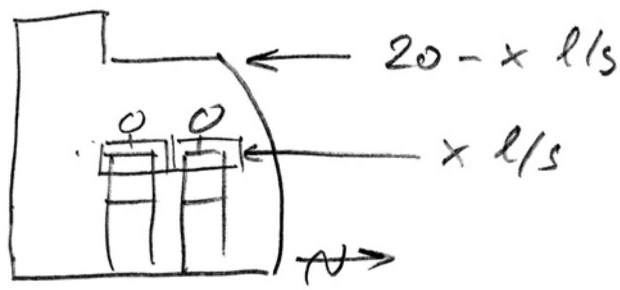



*Figure 3.3. Idea of Mixing Ventilation combined with Personal Ventilation (sketch by prof. Peter V. Nielsen)*

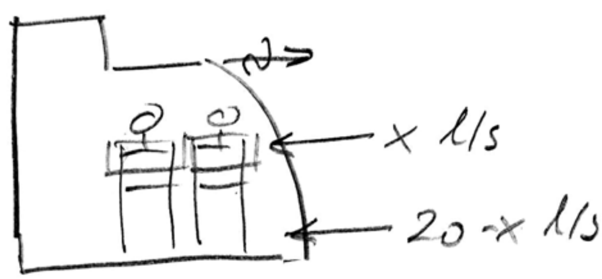
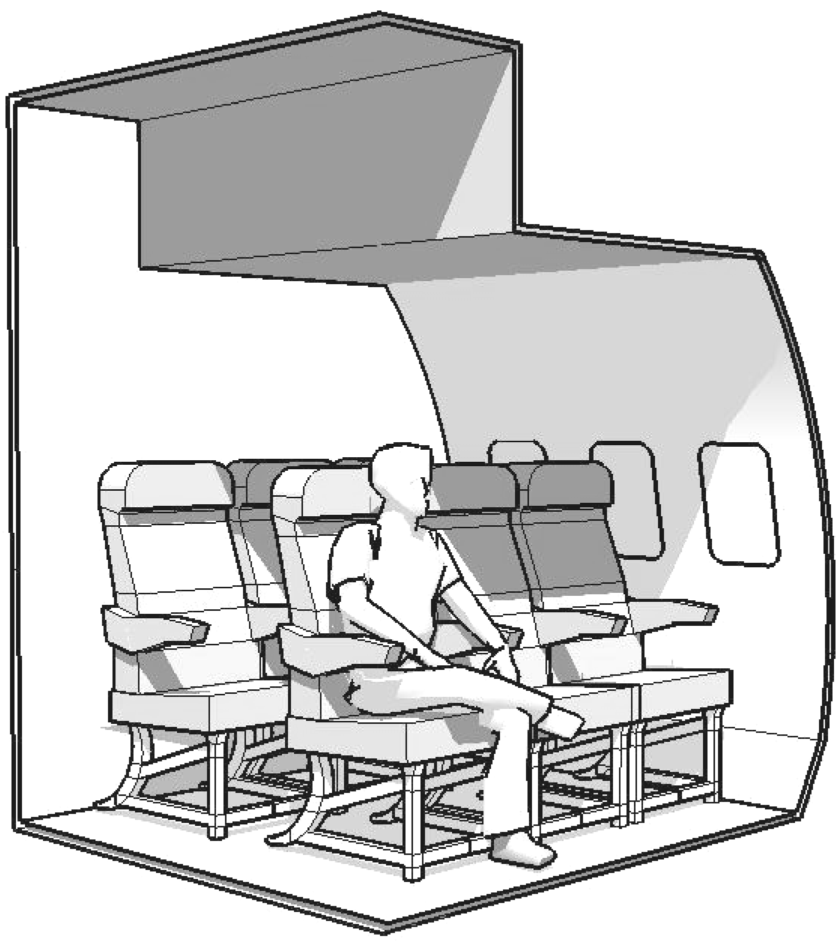



*Figure 3.4. Idea of Displacement Ventilation combined with Personal Ventilation (sketch by prof. Peter V. Nielsen)*

# 4.CHAPTER

# BACKGROUND



## *4.1. Aircraft ventilation*

### 4.1.1. Environmental Control System

Environmental Control System (ECS) is a generic term used in the aircraft industry for systems and equipment associated with ventilation, heating, cooling, humidity or contamination control and pressure.

With continuous development of airplanes, the Environmental Control System evolves simultaneously. Indoor environment in airplanes have to provide safety and thermal comfort for passengers as well as cover their essential physical needs.

ECS engineers convert safety and comfort requirements into components for environmental control system. The ECS comprises the methods and apparatus for controlling the atmospheric constituents and the quality of supplying air, which is resultant of fresh and conserving energy recirculated air.

Complex elements of ECS converse unfit ambient conditions that are quickly changing from ground operations to flight, to a comfortable, safe environment inside.
The quality of the cabin air is maintained by removing excess carbon dioxide and supplying make-up oxygen. The cabin air pressure, temperature and humidity are constantly controlled by ECS which provides good airflow distribution across the cabin as well.

Maintenance acceptable environmental conditions are an unique challenge due to:
- high-density of the passengers
- changes in cabin pressure
- changes outside environment conditions from hot, humidity air with pollutants near the ground to cold, dry and ozoned air during the flight. The temperature can varies from -57°C to 93°C
- varied occupants activities
- contaminated air with particulates and biological particles

Aircraft systems must:
- be light
- be accessible for quick inspection and servicing
- be highly reliable
- tolerate wide range of environmental conditions
- withstand aircraft vibratory and manoeuvre loads
- be able to accommodate failures accruing during flight

[2], [3], [4], [5]

### 4.1.2. Preferred Environment for Comfort

The Federal Aviation Administration (FAA) develops Federal Aviation Regulations (FAR). Part 25 provides designing regulations related to health and safety of the passengers and crew in aircraft in the United States.
In the European countries requirements published by European Joint Aviation Authorities (JAA) are obligatory. The equivalent design regulations are JAR Part 25. However, operating rules based on FAA or JAA regulations are applied individually by the nation of registry.

The most important paragraphs to the ECS design requirements are as follow:

- FAR/JAR 25.831 Ventilation
- FAR/JAR 25.832 Cabin ozone concentration
- FAR/JAR 25.841 Pressurized cabin
- FAR/JAR 25.1309 Equipment, systems and installations
- FAR/JAR 25.1438 Pressurization and pneumatic systems
- FAR/JAR 25.1461 Equipment containing high energy rotors

Typical aircraft ventilation provides approximately 50% fresh air and 50% filtered, recirculated air to the passenger cabin on a continuous basis. That is equivalent to around 5 l/s outside air and 5 l/s recirculated air per passenger.

The minimum value of fresh air in event of loss of one source is 3g/s per person for period exceeding 5 minutes. However, it could be less, but only when environment is not hazardous to the occupants.

Approximately, in every 2 to 3 minute the total volume of air is exchanged in commercial aircraft during standard flight.

High efficiency HEPA filters that cannot be bypassed are used to clean the recirculated air in the 767 airplane and most modern aircraft. This filters can block over 99,9% particles larger than 0,3 µm. Medicine researches prove that most airborne particles are larger than 0,3 µm and those which belong to minority usually form colonies with that cannot pass through the HEPA filter. However, gases which are not removed by filters, are diluted to low levels with fresh air at a high exchange rate of about 12,5 times per hour.

At least 40% of the metabolic carbon dioxide generated by passenger seated in the aircraft cabin is immediately vented outside the aircraft and is not recirculated into the supply air duct.
The concentration of carbon dioxide should not be higher than 1000 ppm.

Acceptable temperature in aircraft cabin is ranging from 18°C to 30°C and it should be controlled to within 1 K. During cruise, the system should maintain a cabin temperature of 24°C with full passenger load in case of hot day ground design conditions. In case of cold day ground operating conditions, the temperature should be 24°C with 20% passengers load.

During whole flight, the cabin must be pressurized to the value, which permits normal physiological functions without supplemental oxygen. The differential pressure control provides a cabin pressure based on equivalent cabin altitude to the flights altitude of the aircraft.

The cabin pressure control system continuously monitors the airplane’s ground and flight modes, altitude, climb, cruise, or descent modes, as well as the airplane’s holding patterns, at various altitudes. This information is transformed, using typical cabin altitude schedule, to control opening and closing the cabin pressure outflow valve situated in the lower aft fuselage.

There are limitation (by aircraft structural design limits) about the maximum pressure difference between the cabin and the outside environmental. Thus, the highest flight altitude is around 12 000 meters and the highest equivalent altitude is 2 400 meters.
The cabin pressure control system panel is located in the pilot’s overhead panel, near the other air-conditioning controls (see Figure 4.1.1.). Normally, the cabin pressure control system is automatic, requiring no attention from the pilots.

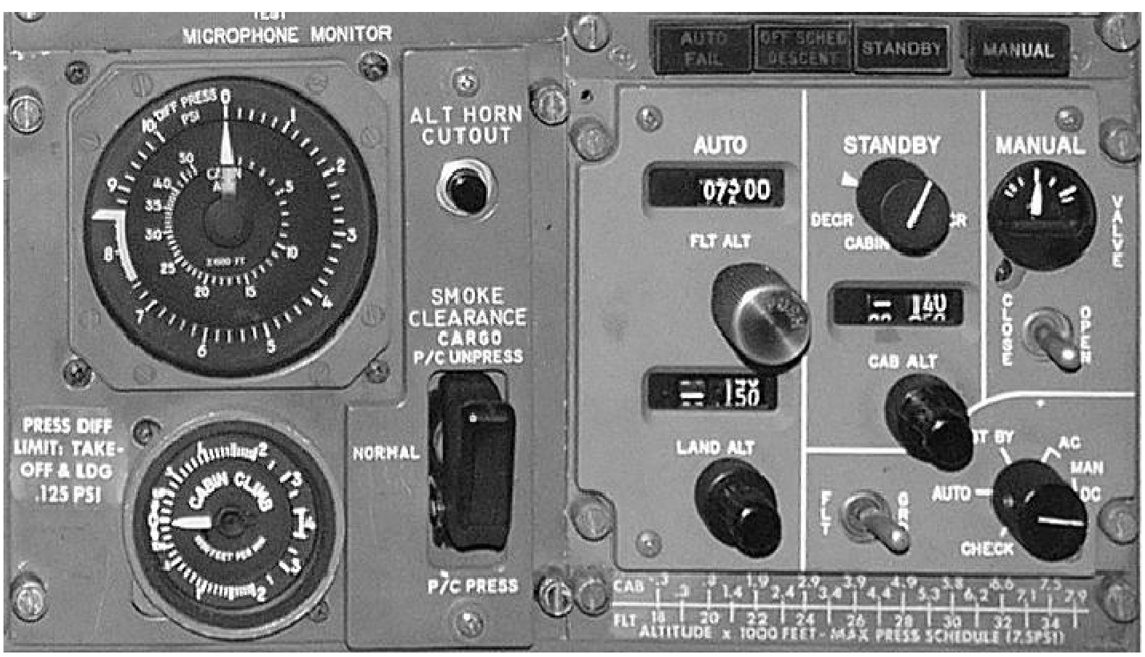



*Figure 4.1.1. Cabin Pressure Control System (CPCS) installed in a 737-200C [13]*

According to velocity, it is determined that most people are comfortable if:

- the average velocity of the airflow near passengers is less than 0,25 m/s
- the maximum velocity of the airflow near passengers is less than 0,33 m/s

[1], [3], [4], [5], [6]

### 4.1.3 Brief description of the aircraft cabin

An aircraft cabin includes curved sidewalls on each side joined by a floor. Then, two rows of seating areas are extended longitudinally at opposite sides of the center aisle. The passenger aircraft are provided with overhead shelf. Thus, the upper zone is delineated between overhead shelf and seating area and limited by sidewall. The upper zone cumulates smoke and other exhalant contaminants produced by passengers.

As two zones are defined in the aircraft cabin, the lower zone is relatively free of contaminants and it is the area proximate the floor of the cabin.

For removing air contaminated by smoke and passengers metabolic exhalants, and to maintain airflow in the cabin stable, the following methods are used:

- preparing mixture of fresh and recirculated air and supplying this pressurized airflow through one or more openings disposed in the cabin
- distributing the supply air within the cabin, however preventing contaminants from mixing with the rest of the air in the cabin
- exhausting contaminated air from upper zone by first exhaust inlet and transporting it through first exhaust duct mainly overboard (by three-way valve)
- exhausting relatively clean air from lower zone by second exhaust inlet and transporting it through second exhaust duct entirely to the recirculating fan

[1]

### 4.1.4 Ventilation system outside the aircraft cabin

Fresh, outside air continuously enters the engine where it is compressed. Then it passes through cooling packs located under the wing center section where it is temperature conditioned and goes to a mixing chamber. In that part of the ventilation system the filtered recirculated air is added in approximately 1:1

proportion to the fresh air. The resultant supply air is transported by air duct, and than split into separate supply lines, travel to the plenums disposed above the ceiling panel. An example of location of exhaust pipes around the cabin is shown in Figure 4.1.2. [1]

First exhaust inlets are in the upper zone, at the opposite sides of the center aisle, and they are connected with first exhaust duct. This air is usually vented overboard through a three - way valve in a back of the aircraft. Although it may be necessary to recirculate a portion of this air to maintain the cabin pressure at its required level, so the valve is connected with return air fan.
The second exhaust inlets are in the lower zone also at the opposite sides of the aisle and they are connected with the second exhaust duct. This air is entirely recirculated into return air fan. The discharge air from fan passes through a filter into mixing chamber.

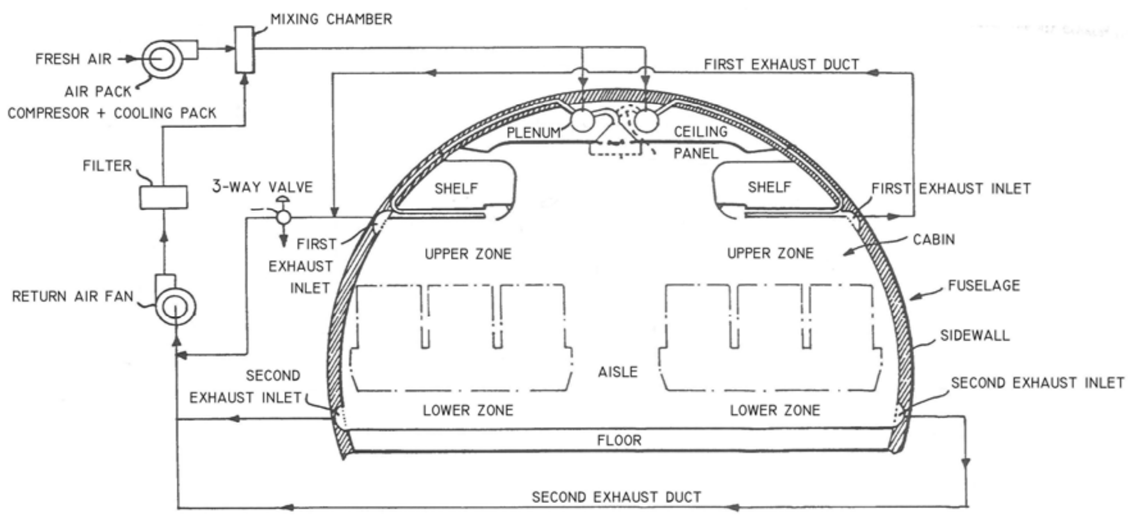



*Figure 4.1.2. Cross – sectional view of an aircraft fuselage with sketch of ventilation system outside the aircraft cabin [1].*

### 4.1.5. Ventilation system inside the aircraft cabin

There are many patents of air distribution inside the aircraft cabin. Most of ideas base on symmetrical airflow distribution in the aircraft cabin, so air is supplied at the same amount to each seat row.
The most common system used in present passenger aircrafts bases on supplying fresh air from two ways. Primary, fresh air enters cabin by the central air supply duct at a relatively high velocity (or in some cases by two air supply ducts). A second supply is delivered by a series of individual nozzles, which are situated generally above middle passenger seat. The nozzles blow a relatively narrow and directed

airflow, which can be adjusted, within the range of volume and direction of supply, according to the individual passenger's needs.

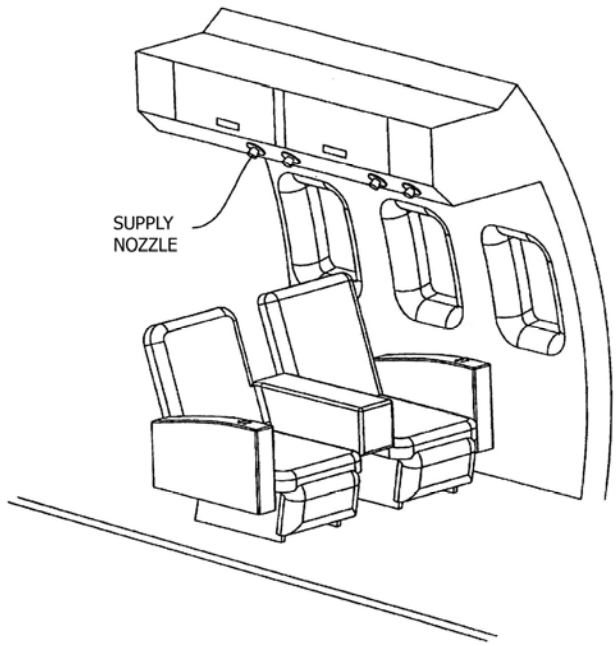



*Figure 4.1.3. Discharge nozzles inside the aircraft cabin [11]*

Going into details, the air nozzle is spherically connected into the housing and has an air passageway with an input end and an output end. Conditioned air, supplied by air ducts, reaches the input end. Then, after passing the output, is blown into the cabin. Each passenger can manually adjust direction of feed air by rotating the spherical outer surface region. In some particular airplanes remote control is used for adjustment process. [11]

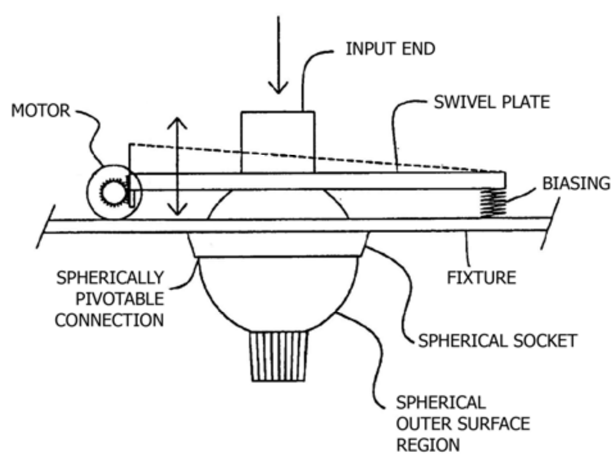



*Figure 4.1.4. Discharge nozzle in details [11]*

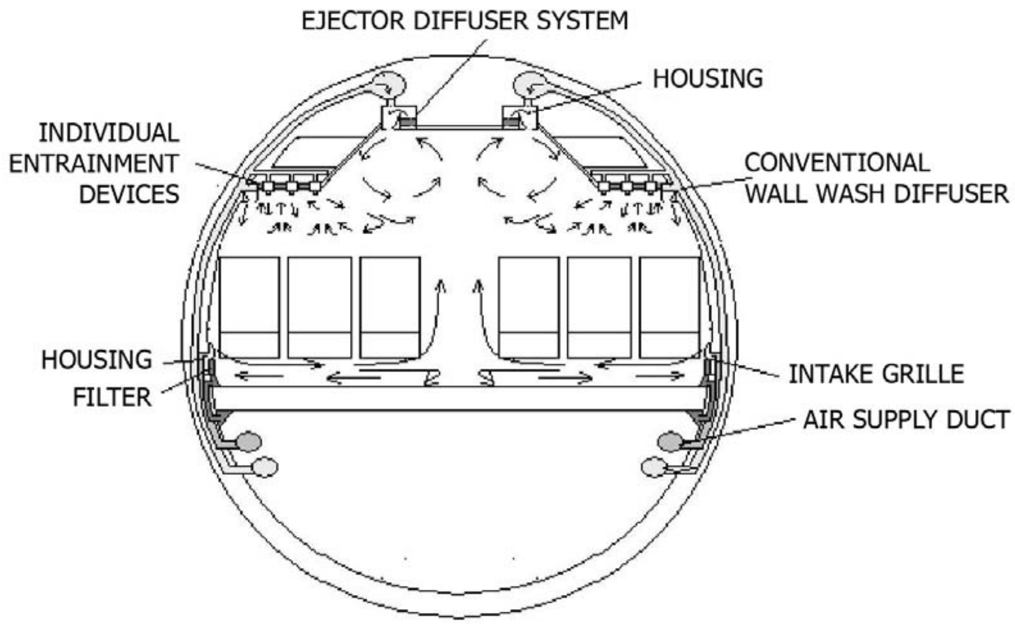



*Figure 4.1.5. Cross – sectional view of an aircraft fuselage with airflow distribution from discharge nozzles and two air supply ducts [12]*

Particular airflow distribution near passengers is shown on another example of ventilation system, which is described in Boeing's patent "Aircraft Cabin Ventilation System". For better understanding, all directions of air transport and reference numerals are shown in Figure 4.1.6.

Supply air plenum is connected with supply air duct disposed in the center of the ceiling, just above the aisle. In addition, supply air duct is covered by a diffuser panel that breaks up directional airflow.

*Airflow movement in upper zone.*
Air flowing out from diffusion nozzle 1 flows generally downwardly into aisle and is drawn laterally, outwardly toward sidewall (as shown in Figure 4.1.6. by arrows nr 1).
The supply airflow thus tends to sweep through the seating area, carrying contaminants from upper zone towards first exhaust inlet.
In the same time, supply air is provided through discharge nozzle 2 and flows laterally, outward through upper zone (as shown in Figure 4.1.6. by arrows nr 2). Contaminated air from upper zone is thus swept from cabin going into first exhaust inlet, situated below the overhead shelf.

*Airflow movement in lower zone.*
Supply air from diffusion nozzle 1 flows downwardly into the lower zone adjacent floor (see arrows nr 3 in Figure 4.1.6.) and is drawn out through second exhaust inlet. [1]

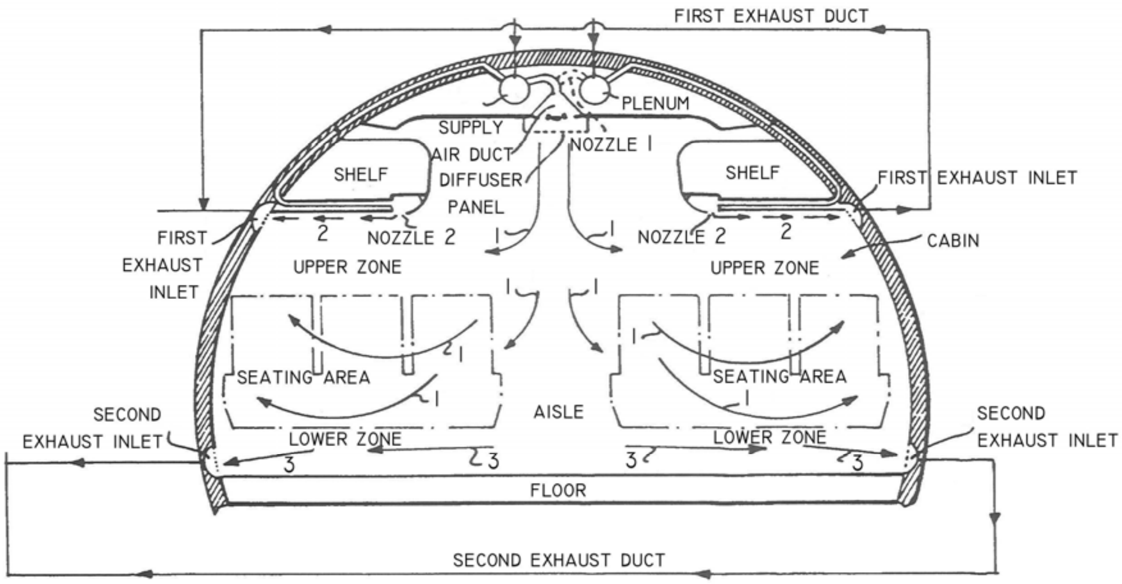



*Figure 4.1.6. Cross – sectional view of an aircraft fuselage with sketch of ventilation system inside the aircraft cabin [1]*

### 4.1.6. Problems occured in ventilation system

It is known that properly working ventilation system in aircraft depends on some factors. This report focuses only on controlling the following ones:

- direction of airflow
- comfortable adjustment the airflow
- relative velocities
- humidity

Manually controlled air conditioning nozzle used in passengers airplanes causes common problem. A short passenger or passenger sitting in the aisle seat must get up from his seat to perform manual manipulation of the nozzle. Furthermore, passenger must predict the volume and direction settings because he is out of his seated position, what means that passenger is not able to feel the effect of his adjustment. This situation makes user repeating the manipulation process several times. Good solution for this inconvenient might be a remote control system to adjust direction and volume of supplied air to each passenger. Nevertheless, this upgrade is not enough if thermal comfort is taken into consideration. It is because nozzles are too far away from passenger’s head and they supply very narrow directed airflow. [11]

Figures 4.1.7., 4.1.8. and 4.1.9. present cases with supply air ducts with conventional type discharge nozzle settled on the ceiling panel. It causes substantial directivity of the airflow. To solve this main problem it is advised to add the diffuser to the end of supply air duct. The velocity has big impact on the airflow in each case. Changes in velocity value can exaggerate or reduce influence of inaccurately designed type of diffuser.

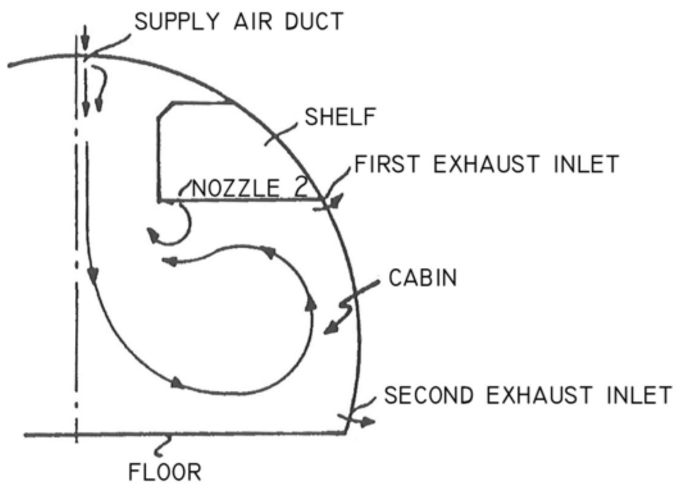



*Figure 4.1.7. First case of airflow distribution*

Figure 4.1.7. illustrates schematically the direction of airflow in half of cabin cross section. Too high air velocity is diffused from supply air duct in comparison to velocity of supply air that enters cabin from nozzle 2. In addition, fully mixing in this setup is not only caused by unbalanced velocity, but also by excessive directionality from supply air duct. Due to that fact, contaminants spread throughout the cabin providing further recirculation of contaminated air.
Increase of the velocity of airflow through nozzle 2 and decrease of the airflow velocity through supply air duct, can be a solution for this problem.

However, taking into consideration advices presented above, it is important not to converse the problem into case from Figure 4.1.8.

Velocity of air discharge from nozzle 2 is too high in comparison to velocity from supply air duct. That causes situation where contaminated air from upper zone is missing the first exhaust inlet (instead of being vented overboard).

The air follows downwardly along the sidewall and than turns round toward the aisle, where is lifted upwardly. That causes similar effect as presented in Figure 4.1.7. - fully mixing.

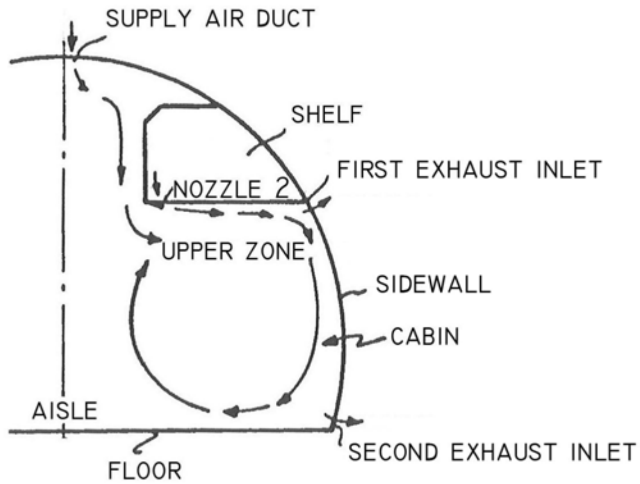



*Figure 4.1.8. Second case of airflow distribution*

Furthermore, contaminated air is drawn through the second exhaust inlet and further recirculated into the cabin.
The solution to this problem is to decrease the velocity of airflow through nozzle 2, and to increase the velocity of airflow through supply air duct.

As two above problems concern mostly the velocity control, Figure 4.1.9. presents airflow, which strictly exposes to the cabin, and in the same time, there is no benefit from nozzle diffuser.

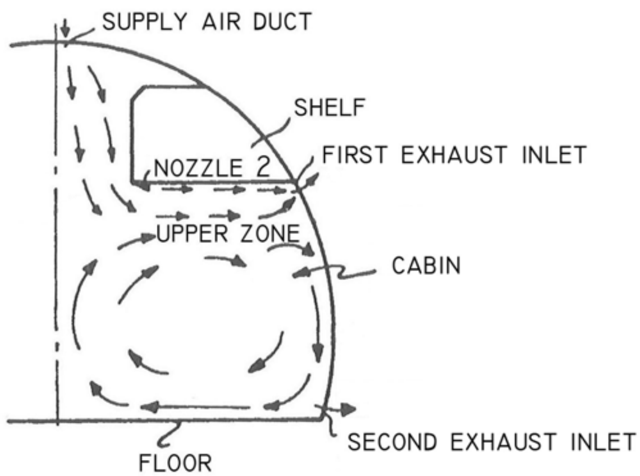



*Figure 4.1.9. Third case of airflow distribution*

Despite the fact that nozzle 2 provides right airflow path towards first exhaust inlet, undiffused supply air duct causes circulation of contaminated air from upper zone within the cabin.
As a result, contaminated air is vent out through the second exhaust inlet and further recirculated back into the cabin.

In fact, whole ventilation system works improperly unless the diffuser is added to the end of supply air duct.

The relative humidity in the cabin ranges from approximately 5% to 35%, with an average of 15% to 20%. Low humidity in the cabin is caused by the frequent renewal of cabin air with outside air, which is very dry. This environment is like inhibitor for fungus and bacterial growth. However, low humidity has unfavorable impact on human causing dehydration of the body through sweating and respiratory water loss. Dehydration can lead to headaches, tiredness and fatigue.
Other negative influence is drying of the nose, throat and eyes. It can also irritate contact lens wearers.

Because of low humidity, there is mostly low level of bacteria and fungi on airplanes. However, the airborne diseases can be transmitted within aircraft cabin if even one passenger is ill.
In 1977, a strain of influenza (A/Texas) infected 72% of passengers and crew because engine malfunction had appeared and the ventilation system had been turned off.

It is noteworthy that 54 persons had spent 3 hours in unventilated space until mechanical problem was solved. The source of disease was one ill passenger.
The investigation of tuberculosis transmission has been made to detect if air recirculation system decrease spreading out the airborne diseases. Evidence indicate that air recirculation system minimize risk of becoming ill.

Summarizing, to avoid mentioned symptoms, it is advised that the airplane ventilation system should never be shut down when passengers are on board and it should focus on continuous prevention from spreading contaminants and infections.

Moreover, diffuser is necessary at the end of supply air duct and balanced values of velocities have to be designed. Due to passengers' inconvenience, it is advised to use different kind of personal ventilation diffuser than nozzle above the passenger's head or at least provide remote control of supply air for each passenger.

It is also good to realize that optimal velocity values should be designed, because too high velocity influences thermal comfort of the passengers. Optimal velocity values are shown in Chapter 4.1.2.

Air quality should follow the FAR/JAR standards otherwise the passengers and crew might experience:

- fatigue
- headaches
- nausea
- dizziness

- respiratory problems
- some chest pain
- nasal congestion
- eye and nose irritation

References: [1], [3], [7], [8], [9], [10]

## 4.2. Displacement Ventilation

Displacement Ventilation (DV) is getting more and more popular around the world. In many cases this system makes it possible to obtain better quality of air within less energy consumption than mixing ventilation. Contaminations are not fully mixed with fresh air but displace from occupied zone. Well design DV works very efficiently both in industry as well as in public buildings.

The idea of this system is based on creating two different zones of air in a room. It is possible due to different density of clean and contaminated air. Lower zone – the occupation zone (up to 1.1m from the floor level in case of sitting job, or 1.8m for standing job) is clear zone. Above this zone is a contaminated one. To achieve this system of air distribution we need to supply low-turbulent air directly into the occupied zone (working area is the area where displacement inlets are located). Temperature of fresh air should be 1-5 K lower than air room temperature, and velocity shouldn't be higher than 0,2 m/s. The air is spread along the floor practically in a horizontal layer, and when meet warm surface, thermal plumes transport the air upward, above the occupied zone, to the second zone, where exhausts are located (see Figure 4.2.).

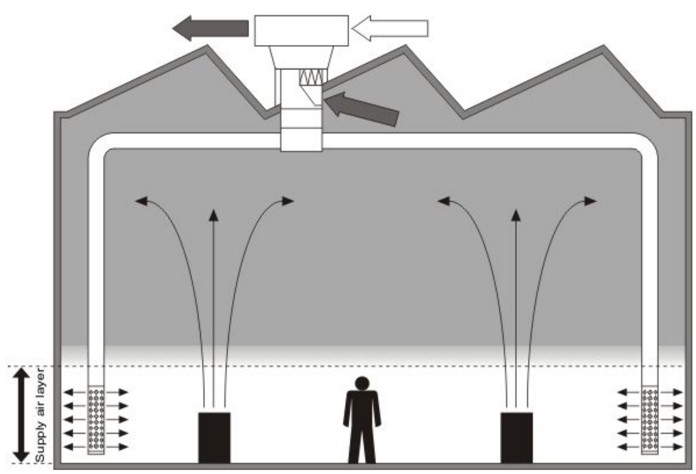



*Figure 4.2. Functional diagram for stratification ventilation [14]*

The same mechanism applies to heat and contaminants (if the contamination is connected with heating source) from lower levels. Due to man's activity, hot air, which is located close to human surroundings, is also transported upwards, what allows to obtain very good air comfort in a room. If velocity of distribution fresh air will be higher than 0,2 m/s, people in occupied zone would feel thermal discomfort due to draught, and too big temperature gradient. In lowest layer (from 0,1m to 1,1m above the floor), according to ISO 7730, temperature gradient should not be higher thane 3ºC/m.

Advantages of Displacement Ventilation are:

- air stratification prevent mixing fresh air with contaminated air (polluted air does not get to 'working area')
- relatively small velocities (low level of noise in installations)
- smaller design chill capacity (it is not necessary to consider heat generated above occupied zone while counting heat incomes)

Disadvantages:

- feeling of draught in diffusers area
- while having a big heat supply in a room, the large temperature difference between supplied air and indoor air, is considered by humans as negative conditions
- big size of diffusers and an open space restriction in diffuser area (what should be taken into consideration on the designing stage in cooperation with architects)
- not suitable for heating (due to stratification)

[5], [14], [15], [16]

## *4.3. Mixing Ventilation*

Mixing Ventilation is other, next to Displacement Ventilation, mechanical system of providing fresh air into occupied zone and getting out contaminated air. The target of this system is to supply air draughtlessly into the space, causing mixing of air, so the thermal conditions and contaminations concentrations are the same either in the entire space or in the occupied zone.

Heat and humidity are taking into consideration in order to rate the airflow. However, sometimes the airflow rate is based on the dilution of emitted air contaminants in the space via air exchange.

Mixing Ventilation is the most common system used in industry, public buildings; offices, etc (while Displacement Ventilation in concert halls, libraries, etc.)

The following factors are crucial meaning on the air diffusion:

- Air flow rate
- Diffuser type, jet type and direction
- Diffusers locations
- Difference of temperature between supply and ambient room air
- Distance between walls and ceiling
- Interaction with other air jets or air plumes – e.g., convective plums from warm/cold surfaces
- Exhaust location (only in some cases – avoid short-circuiting)

There is no limitation for the diffuser type. They can be grills, slots, valves etc. Type as well as a number is selected to obtain proper ventilation effectiveness, acceptable air velocity conditions (what is very important for comfortable thermal conditions), with acoustic requirements respected.

Pluses of using mixing ventilation:

- Sufficient supply and exhaust air flow rates
- Diffuser and jet type selection adapted to the operation conditions throughout the year
- Wider range of diffuser's type
- Adaptable positioning of supply and exhaust units
- Vertical or horizontal zoning when it is useful to limit the air diffusion into part of the space only

Minus of using mixing ventilation:

- Mixing fresh air with potential contaminations

[5], [17]

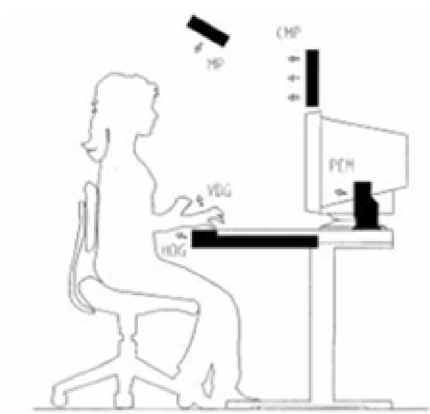
## *4.4. Personal Ventilation*

### 4.4.1. Basic information

Research publications have proven that Personal Ventilation is very efficient system to protect humans beings from cross infection. It reduces the amount of pollutants that people are exposed to, minimizes the danger caused by infectious agents, improves inhaled air quality and, what is most significant, gives the users possibility of creating their own comfortable environment. Everything thanks to providing clean and cool air close to each occupant's breathing zone.

According to differences in clothing, activities, individual preferences for air temperature, always lead to different peoples' responses to thermal comfort. Preferred temperature can differ as much as 10°C and the movement of air (air velocity) more than four times. That explains all complaints about indoor environment. Using PV each occupant can optimize and control temperature, flow rate (local air velocity) and direction of supplied air according to their own need and preference, and because of that, improve their comfort conditions.

Fresh air could be supplied to the breathing zone in many ways using the supply air terminal devices (ATD). Figure 4.4.1. presents the most commonly used devices e.g. Movable Panel MP, Computer Monitor Panel CMP, Vertical Desk Grill VDG, Horizontal Desk Grill HDG and Personal Environments Module. [20]




*Movable Panel (MP),*
*Computer Monitor Panel (CMP),*
*Vertical Desk Grill (VDG),*
*Horizontal Desk Grill (HDG),*
*Personal Environments® Module (PEM)*

*Figure 4.4.1. Examples of tested air supply terminal devices (ATD) [20]*

Numerous laboratory measurements, show that efficient ATD (of different designs which allows controlling air flow rate and some of them also flow direction), providing almost 100% of clean cool air, gives the effectiveness of 50-100%, which is 1-2 times higher than the results of mixing or displacement ventilation alone.
The effectiveness increases when fresh air supplied by ATD is cool. The differences in regard to acceptability of the inhaled air decrease over time due to adaptation, but remain always higher with personalized ventilation than with only mixing ventilation (Figure 4.4.2.). Furthermore, the temperature of the inhaled air might be decreased (by up to 6°C) in comparison with mixing ventilation, what could further improve perceived air quality. [21]

While providing more fresh air to the room we can cause discomfort due to draught. Air movement in the surroundings of a human body affects its thermal sense. Personalized Ventilation allows avoiding it by controlling airflow rate and its direction. Personalized flow of air towards the face is usually more preferable than the airflow towards the abdomen. From economical aspect, the breathing requirements of sedentary occupants are as low as 0.1 l/s, while total volume ventilation supplies a hundred times more air. The optimal personalized airflow rate is 3 - 20 l/s, and the local air velocity (draught) 0.2 - 1.2m/s. However, when the ambient temperature is higher than 26°C, the cooling capacity of the personalized ventilation directed to the breathing zone may not be sufficient enough to provide thermal comfort for some people without causing draught discomfort.

Nowadays, diseases that are transported with air are common. This problem was clearly demonstrated in case of SARS, which had worldwide outbreak in 2003. SARS rapidly spread around the globe because of infected people who were traveling around the world in aircraft.

It is necessary to add, that properly designed and working personalized ventilation prevents transmission of contagious diseases between occupants, which can be crucial for their protection. There are three main ways of spreading airborne infections between people. The first one is a face-to-face contact (surface contact). It happens in case of common cold or influenza. The second one is large-droplet sprays (cough, sneeze) and the last one is a transmission through air movement (infectious aerosols exhaled by occupants).

According to the research done on this topic, PV combined with mixing ventilation is always superior than mixing ventilation alone, when considering residents' comfort and cross infection protection. The situation is slightly different in rooms with displacement ventilation (or under floor ventilation), what we were trying to investigate.

The personalized ventilation causes mixing of exhaled air with indoor air, which increases the risk of transmission of contagion to occupants who are not protected by efficient personalized ventilation. Index $R_{A0,}$ which is defined as a reproductive number, illustrates the number of secondary infectious agents that arise when a single infectious case is introduced into a population where everyone is susceptible. If $R_{A0} > 1$ an infection can spread in a population, the larger the value of $R_{A0}$ is, the more likely is the infection to increase rapidly. Figure 4.4.3. demonstrates different $R_{A0}$ in a room for mixing combined with personalized ventilation and for only mixing ventilation. [21]

From the economical aspects, it is also important to add, that personalized ventilation is an energy efficient system in comparison with total volume ventilation.

Smaller volume of air supplied and the possibility of turning on and off, according to workplace occupation, lead to significant energy savings. This is also criteria in The Leadership in Energy and Environmental Design (LEED) Green Building Rating System™, which encourages and accelerates global adoption of sustainable development. [22]

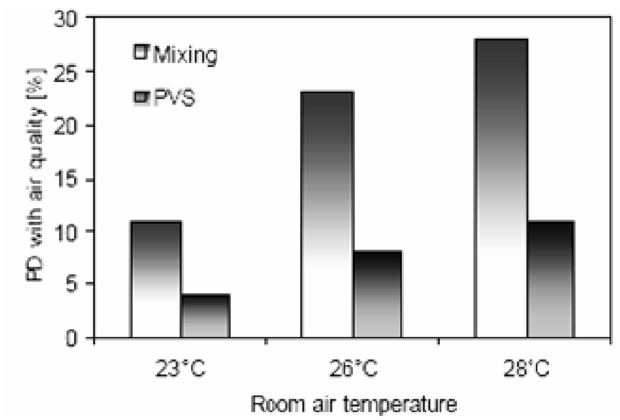



*Figure 4.4.2.*
*Percentage of dissatisfied people (PD) with air quality in a room with mixing ventilation alone (left bars) and when provided with PV at room air temperature of 23, 26 and 28ºC. Personalized air temperature is 20ºC. Occupants are provided with individual control of personalized flow rate. The total amount of air supplied to the room (only clean air) is the same with mixing ventilation alone and with PV combined with mixing ventilation. [21]*

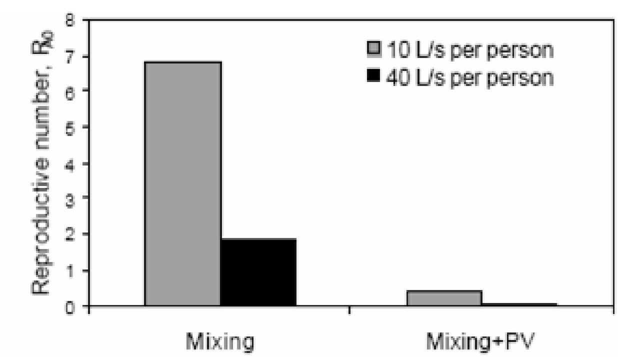



*Figure 4.4.3.*
*Reproductive number ( $RA_0$) in a room with mixing ventilation alone and mixing ventilation combined with PV. In case of mixing + PV minimum of 10 L/s·person and maximum of 15L/s·person of outdoor air is supplied through the PV and the rest through the mixing ventilation. [21]*

### 4.4.2. PV – occupant-related performance criteria

The following criteria are decisive factors based on health, comfort and productivity:

- Improvement of thermal comfort without causing draught discomfort
- Improvement of inhaled air quality (clean air at low enthalpy)
- Protection from and minimizing airborne transmission of infectious agents
- Minimal disturbance of the microenvironment of neighboring workplaces and the ambient environment
- Independence of its performance of occupant's movement and body posture at the workstation
- Easy control
- Ergonomics, appearance, energy efficiency, initial installation cost, maintenance, etc. [5]

### 4.4.3. PV – occupant-based design consideration

To obtain optimal performance of PV, two significant factors must be considered to achieve preferred air quality and thermal comfort. The first one – the aerodynamic characteristics of personalized flow of fresh and cool air, and the second one – the interaction of this flow with the free convection flow around the occupant's body, the ventilation flow generated by the total volume mechanical ventilation and the transient flow of exhalation (Figure 4.4.4.). Other things such as thermal plumes from office equipment (printers, PCs, photocopy machines), flows generated by its fans, draught from windows (which usually are one full wall of open-space offices) may also have some impact on the proper PV. [19]


1 – free convection flow,
2 – personalized flow,
3 – respiration flow,
4 – ventilation flow,
5 – thermal flow.

*Figure 4.4.4. Airflow interaction around human body [19]*

## *4.5. Types of airflow*

It is possible to differ several types of air movements. The free convection flow around the body, the flow of breathing, the flow from air terminal devices and the flow from conventional systems are the most important ones. The interaction of these affects thermal comfort and quality of inhaled air.

- Free convection flow around the human body

This upward airflow is observed in a steady environment. Within a thin boundary layer at the lower parts of the body, the free convection flow is laminar. Then it becomes turbulent within a thick boundary layer at the height of the occupant's head. Airflow depends on the shape of the body, posture and room temperature. The mean velocity can be as high as 0.25 m/s and the thickness of the boundary layer may measure more than 0.2 m. This flow induces and transports air (often with pollution) from lower levels upward to the breathing area. [20]

- Personalized flow

Usually personalized flow is nothing but a free jet issued from a circular or rectangular opening or a nozzle. Cool and fresh air flows through the core section (main section of the jet) with a constant velocity and low turbulence intensity. The length of the core jet increases with the Reynolds number (Re). However, for Re>3x104 the core is independent of Reynolds number. The buoyancy effect increases along with temperature difference between supplied air and surrounding air. It decreases along with increase of velocity of the supplied air.

- Ventilation flow

The air from mixing ventilation is supplied with a high velocity, which makes the air inside a room fully mixed. The generated flow depends on the supply air temperature, the location and type of air supply devices and also heat sources. When it reaches the occupied area, the air velocity is small in comparison to the velocity of thermal flows generated by heat sources. However, the concentration of contaminants generated in the room is the same everywhere because the air is fully mixed. Displacement ventilation, on the other hand, spreads fresh air over the floor. The free convection flow takes the supplied air from lower heights up to the breathing zone.

[5], [18], [20]

## 4.6. Indoor Air Pollution

### 4.6.1. Environmental Tobacco

Environmental Tobacco Smoke (ETS) is mixtures of particles, which construct smoke exhaled by the smoker, and are emitted during burning end of a cigarette, pipe, or cigar.

Smoke can contain more than 4,000 compounds, including carbon monoxide and formaldehyde. At least 250 of them are known to be harmful and 50 are carcinogens. These compounds may increase discomfort and irritation of eyes, nose and throat.

Furthermore, ETS may cause long - term health effects. An exposure to ETS is often called "passive smoking".

In 1986 the National Academy of Sciences recommended banning smoking on US domestic flights except for flights over six hours to or from Alaska or Hawaii because of possibility of fires and potential health hazard.
Airlines started to introduce bans in the late 1990s. Since 2000, all of the world's busiest international routes have been essentially smoke-free. Within the US, the government has banned in-flight smoking for almost two decades.
Nowadays, it is extremely rare that smoking is allowed during the flight. However, in this case it is necessary to control ETS in the aircraft cabin. Actually, knowledge does not know neither the direct way to measure ETS nor standards for that. Thus, indirect methods are used focus on control the concentration of tracer constituents of ETS such as carbon monoxide (CO) and respirable suspended particulates (RSP).

92 randomly selected airplanes were tested in a DOT - sponsored study to check if permissible exposure limit for RSP and CO is norm – preserving. Measurements were made during peak smoking. Level of CO was averaged 0.5 to 2 ppm while The Federal Aviation Administration (FAA) specifies a limit for CO of 50 ppm. The RSP concentration results noted averaged value of 40 mg/m3 and 175 mg/m3 in nonsmoking and smoking section, respectively.The permissible exposure limit for RSP is specified by The Occupational Safety and Health Administration and it is set at 5,000 mg/m3 for RSP.

However, in reality, there is no safe level of exposure to Environmental Tobacco Smoke. Studies have shown that even low levels of ETS exposure can be harmful. Thus, only completely eliminated smoking in indoor spaces provide fully protection to nonsmokers from ETS.
Highly efficient recirculation filters can remove nearly all of the tobacco smoke particulates from the recirculated air but they are permeable for gases such as CO. Also separating smokers from nonsmokers, cleaning the air, and ventilating do not provide maximal effectiveness.

[3], [5], [9] [23], [24], [25]

### 4.6.2. Gaseous pollutants of combustion sources

Aside from ETS the important combustion pollutants such as carbon monoxide (CO), nitrogen dioxide (NO2), sulfur dioxide (SO2) are produced in indoor environments from malfunctioned heating devices or inappropriate use of such devices.

**Carbon Monoxide**

Carbon monoxide is a highly toxic odourless and colourless asphyxiant. Inhalation of CO causes a throbbing headache because hemoglobin has about 240 times grater affinity for CO than for oxygen disrupting oxygen transport.
Carbon monoxide easily combines with haemoglobin. The product of this reaction is carboxyhemoglobin (COHb) which disrupts oxygen transport in the organism and influences human health and perception.
The table below shows relationship between reaction and different COHb levels in blood.

| *% COHb in blood* | *Effects Associated with COHb Level* |
|---|---|
| 80 | Death |
| 60 | Loss of consciousness; death if exposure continues |
| 40 | Confusion; collapse on exercise |
| 30 | Headache; fatigue; impaired judgment |
| 7 - 20 | Statistically significant decreased maximal oxygen consumption during strenuous exercise in healthy young men |
| 5 - 17 | Statistically significant diminution of visual perception, manual dexterity, ability to learn, or performance in complex sensor - motor tasks (such as driving) |
| 5 - 5.5 | Statistically significant decreased maximal oxygen consumption and exercise time during strenuous exercise in young healthy men |
| below 5 | No statistically significant vigilance decrements after exposure to CO |
| 2.9 - 4.5 | Statistically significant decreased exercise capacity (i.e., shortened duration of exercise before onset of pain) in patients with angina pectoris and increased duration of angina attacks |
| 2.3 - 4.3 | Statistically significant decreased (about 3 -7%) work time to exhaustion in exercising healthy men |

*Table 4.6.1. Carboxyhemoglobin (COHb) levels and related health effects [26]*

**Nitrogen dioxide**

This corrosive gas has pungent odor and it affect the mucosa of the eyes, nose, throat cause shortness of breath. Staying in a place with extremely high concentration of $NO_2$ for example in a building fire may result in pulmonary edema and diffuse lung injury. High – dose exposure of $NO_2$ endangers people’s health directly causing lung damage and indirectly causing health effects by increasing host susceptibility to respiratory infections. It is noteworthy that people with asthma should even avoid low levels of $NO_2$ because it can cause increased bronchial reactivity. Long-term exposure to high levels of $NO_2$ can contribute to chronic bronchitis.

**Sulfur dioxide**

Sulfur dioxide $S0_2$ is a colorless gas with pungent odor. It can be reported from about 0,5 ppm. $S0_2$ belongs to the family of sulfur oxide gases ($SO_x$). These group dissolves easily in water so $SO_2$ readily reacts with moisture in the respiratory tract causing irritation of upper respiratory mucosa. $SO_2$ and nitrogen oxides react with other substances in the air to form acids, which fall to earth as rain, fog, snow, or dry particles. Sometimes they may be carried by the wind for hundreds of kilometers.

[26], [27], [28]

### 4.6.3. Carbon dioxide

Carbon dioxide is the product of human metabolism that is exhaled during breathing process. This simple asphyxiant gas is major air pollutant of aircraft cabin and is used as an indicator of indoor air quality.

Concentration of $CO_2$ in the cabin depends on:

- concentration in outside air
- outside air rate using in aircraft ventilation system
- number of passengers and crew
- activity level of occupants
- diet and health of people (low impact)

Table below shows $CO_2$ production by adults. Children produce 70% of these values.

| | |
|---|---|
| Rest in lying position | 10 - 12 l/h |
| Rest in sitting position | 12 - 15 l/h |
| Office work | 19 - 24 l/h |
| Average heavy work | 33 - 43 l/h |
| Sport activities | 55 - 70 l/h |

*Table 4.6.2. Exhaled CO2 by adults [29]*

When concentration of $CO_2$ exceed 35 000 ppm, central breathing receptors are triggered and cause the sensation of shortness of breath. Progressive higher concentrations are a beginning for central nervous system dysfunction because of displacement of oxygen.

According to the American Industrial Hygiene Association, if $CO_2$ levels reach 800 ppm, people starts to complain about the comfort level. However, The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) recommends a concentration of $CO_2$ no more than 700 ppm.

Additionally, The Occupational Safety and Health Administration (OSHA) and the American Conference of Governmental Industrial Hygienists (ACGIH) have set workplace safety standards depending on time of exposure. Thus, for 8-hour time weighted average (TLV - TWA) the maximal value is 5000 ppm and it is 30 000 ppm for short-term exposure level (STEL).

The TLV-TWA is the average concentration for a normal 8-hour workday, 40-hour workweek to which nearly all workers may be exposed repeatedly, day after day, without adverse effects. The TLV-TWA is usually averaged over 8 hours, which is used as the standard daily work shift. 8-hour workday means 40-hour workweek to which all workers should work without adverse effects. The STEL is the maximum concentration for continuous exposure for a 15-minute time period.

[3], [28], [29], [30]

### 4.6.4. Animal danger, Molds, Dust Mites, Other Microbial Aerosols

Biological air pollutants are found in every home school and workplace. The most common biologically derived particles that belong to airborne pollution are: [23]

- viruses
- bacteria
- fungal spores
- hyphal fragments
- arthropod fragments
- droppings

Damp surfaces and malfunction of ventilation system especially in the bathroom provide perfect conditions for microorganisms' growth (especially fungal, molds). Intensity of malodorous volatile chemicals production depends on relative humidity, temperature, oxygen, pollutants, ozone and ultraviolet light. [28]

Examples of main diseases caused by biological air pollutants: [5]

- Tuberculosis
- Legionnaires' Disease
- Allergic Reactions
- Hypersensitivity Pneumonitis
- Humidifier Fever
- Mycotoxins

**Legionella**
Legionnaires' disease is an uncommon form of pneumonia caused by the legionella pneumophilia bacterium. People catch Legionnaires' disease by inhaling small droplets of water suspended in the air, which contain the bacteria. However, most people exposed to legionella do not become ill. This potentially fatal form of pneumonia mainly affects people over 50 years of age, and generally men more than women. Smokers and ill people are at a higher risk. Legionnaires' disease is hard to detect because symptoms are similar to the flu. [31], [32]

The following conditions increase growth of Legionella: [31]

- optimal temperature 37°
- a source of nutrients for the organism like sludge, scale, rust, algae, and other organic matter
- high humidity (at least 65%)
- high carbon dioxide concentration (2,5-5%)

The bacteria cannot be spread from person to person but they are widely distributed in the following environment: [32]

- natural water as rivers and streams
- showers, sinks, fountains
- cooling and air conditioning systems
- hot and cold water systems and spa pools

### 4.6.5. Volatile Organic Compounds

Volatile organic compounds (VOCs) are carbon - based solvents that easily evaporate into gaseous forms at room temperature. These chemicals are widespread all over the word as well in industry applications as in private households. [33]

The European Communities determines volatile organic compound (VOC) as any organic compound which perform the following requirements: [34]

- temperature of 293.15 K
- a vapor pressure at least 0.01 kPa
- corresponding volatility under the particular condition of use

VOCs include variety of chemicals: formaldehyde, pesticides, solvents or cleaning agents. Those substances are emitted by:

- personal items such as scents and hair sprays
- household products such as finishes, rug and oven cleaners, paints and lacquerers, paint strippers
- dry - cleaning fluids
- building materials and home furnishings
- office equipment such as some copiers and printers
- office products such as correction fluids and carbonless copy paper
- graphics and craft materials including glues and adhesives, permanent markers, and photographic solutions

Signs and symptoms of VOC exposure may include conjunctively irritation, nose and throat discomfort, headache, dizziness and also dyspnea or vomiting.
It is noteworthy that any standards exist for exposure to VOCs in nonindustrial indoor environments. [5]

#### 4.6.6. Sick Building Syndrome

The term "sick building syndrome" (SBS) describes a situation in which reported symptoms among population of building occupants can be associated with their presence in that building.

Typical complaints are eye and nasopharyngeal irritation, rhinitis or nasal congestion, inability to concentrate, and general malaise complaints.

A 1984 World Health Organization report suggested that as many as 30 % of new and remodeled buildings worldwide might generate excessive complaints related to indoor air quality. [27]

## *4.7. Breathing function*

### 4.7.1. Basic information about Breathing

Respiration creates energy in the form of energy-rich molecules such as glucose. That is why normal cellular metabolism requires a continuous supply of oxygen $O_2$ and continuous disposal of carbon dioxide $CO_{2.}$ The major responsibility of the respiratory system is to ventilate gas-exchanging surface and thus add $O_2$ and remove $CO_2$ from the blood passing through the lungs.

Average human lungs can hold approximately 6 litres of air, however, what is most interesting only a small portion of this amount is used during normal breathing. Minute ventilation also called the total ventilation, is equal to the product of the normal respiratory rate (12 breaths per minute) and the normal tidal volume (500 ml) what gives 12 breath * 500 ml = 6 liter per minute and is about 6000 ml/min. The same values are set up in artificial lung during all our measurements. [35]

The total lung capacity varies between persons and is related to the person's sex, age, weight and the degree of physical activity.

### 4.7.2. The Process of Breathing

There are three phases of whole process of breathing:

a) *Inhalation* (the active phase during which air is drawn into the lungs);
b) *Exhalation*, (the passive phase of breathing during which air is expulsed from lungs);
c) *Resting,* (phase between inhalation and exhalation);

The time ratio between inhalation, exhalation and resting are shown in Table 4.7.1.

| *Inhalation* | *Exhalation* | *Resting* |
|---|---|---|
| 1 | 1. 5 | 1 |

*Table 4.7.1. Time ratio of respiration*

The pulmonary airways consist of three different parts (see Figure 4.7.2.). First, the upper airways, extending from the nares and the lips to the larynx. Here, the air is warmed and moistened. Secondly, the conducting airways where the air is distributed in the lungs in a branched-tube network starting at the trachea and extending to include the terminal bronchioles. Third, the respiratory zone that begins with the respiratory bronchioles ends with the alveoli (little air sacs). Here, the gas exchange takes place [36].

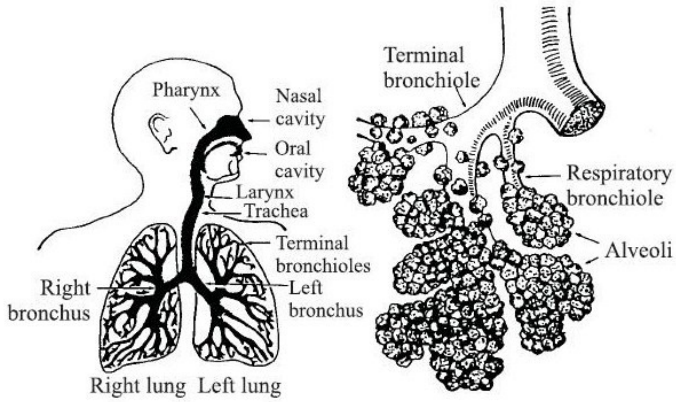



*Figure 4.7.2. Major anatomical features of the human respiratory system. (Turiel, 1985)*

The state of the air in the lungs is 37°C and 100% rh at barometric pressure, while the exhaled air is usually approximately 34°C and 100% rh.

Breathing not only results in the loss of carbon dioxide but also in the loss of water from the body. Exhaled air has a relative humidity of 100% because of water diffusing across the moist surface of breathing passages and alveoli. The content of water vapour is not stable as it depends on several factors. Comparison of the content of inhaled and exhaled air is presented in Figure 4.7.3.

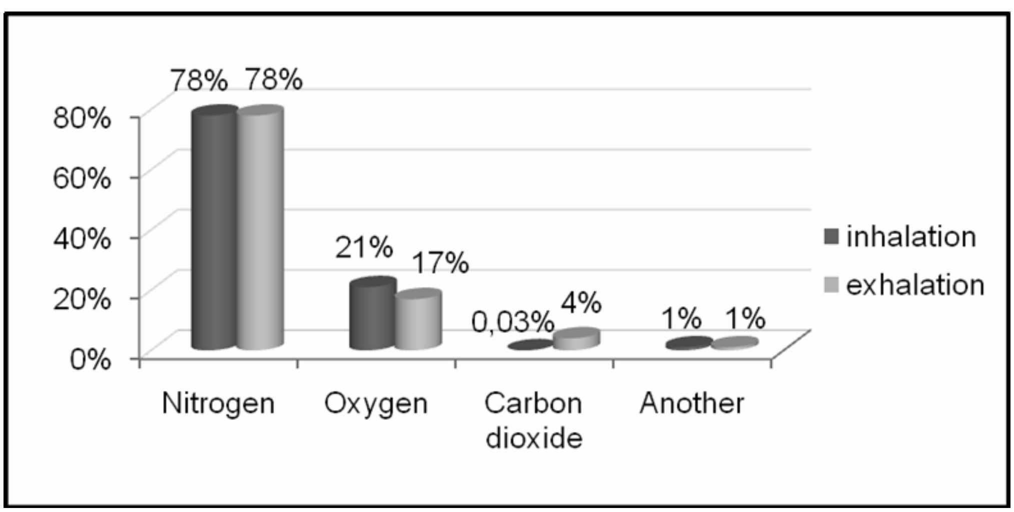



*Figure 4.7.3. Percentage content of the inhaled and exhaled air [37]*

### 4.7.3. Respiration flow

The pulmonary ventilation (4.7.4.) is defined as the volume of air, which is exhaled per minute. The definition says, that pulmonary ventilation equals the frequency of respiration multiplied by the mean expired volume [36]

*Ventilation Equation*

$$\dot{V}_{res} = \dot{f}_{res} \cdot \overline{V_T} \qquad [4.7.4.]$$

where:
$\dot{V}_{res}$ - Pulmonary ventilation (l/min)
$f_{res}$ - Frequency of respiration ($min^{-1}$)
$\overline{V_T}$ - Mean expired tidal volume (l)

The frequency of respiration and pulmonary ventilation are not constant and depend on the activity level of the person. The example of typical level of the three above mentioned parameters are shown in Table 4.7.2.

| *Activity level* | *Tidal volume (litre)* | *Frequency ($min^{-1}$)* | *Pulmonary ventilation (litre/min)* |
|---|---|---|---|
| Rest | O,5 | 12 | 6 |
| Moderate work | ~2,5 | 12 | 30 |
| Maximal work | ~3,0 | 30-40 | 90-120 |

*Table 4.7.2. Examples of tidal volume, frequency of respiration and pulmonary ventilation for different activity levels [36]*

The velocity of exhaust is high in the mouth/nostrils (even up to 1 m/s), but near the face it is lower and it decreases rapidly as the distance from the face increases. The flow generated by exhalation/inhalation depends on the mode (nose/mouth, mouth/nose), breathing flow rate (according to activity level, human's posture, etc.) shape of nose and mouth shape. Flow of exhaled air, with temperature of 34ºC and humidity of 100%, can penetrate and affect free convection flow. [36]

### 4.7.4. Thermal manikin breathing function

Thermal manikin called 'Comfortina' is connected to artificial, to simulate human breathing function. Detailed description of these equipments can be found in Appendix B 'Equipment'.

The system mentioned above can be set to breathe through the mouth and/or nose. Also, the respiration frequency and pulmonary ventilation is adjustable. To be as similar as it is possible to human, 12 breaths per minute with tidal volume of 500 ml per each breath are set up during all our measurements.

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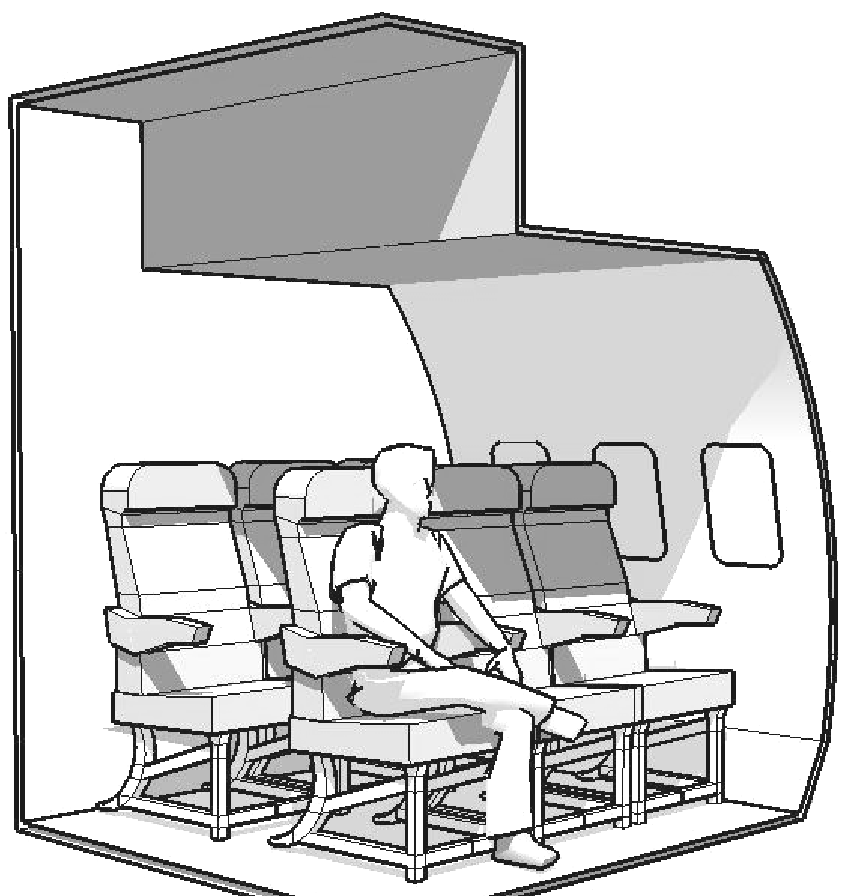
# 5.CHAPTER

# CONCEPT OF PERSONAL VENTILATION DIFFUSERS



Measurements in this project are based on three different PV diffusers. All of theme base on similar construction. They were design to protect aircraft passengers from cross infection and airborne contaminants, as well as supply them with fresh air.
The principles were mentioned in P. Jacobs and W. de Gids's article from Indoor Air 2005, "The aircraft seat as indoor air quality and temperature control system". In this report the results of measurements to quantify the convection induced airflow around a seated person and the effect of this flow on the trajectory of a local supply jet were described.

One of the ideas behind personal ventilation diffusers is that it stays in close contact with human skins and breathing zone. Moreover, it is possible to create proffered microenvironment and thermal condition according to occupant's needs.

[3], [4]

## *5.1. Seat Strap*

This diffuser is design to protect traveling passengers during daytime flights. It is only considered to be a prototype. In a final solution, the air supply will be integrated with the seat.

It is possible to divide three parts (separately supplied with fresh air through four nozzles):

- the top part behind the head
- the middle part behind the back
- bottom part on the seat

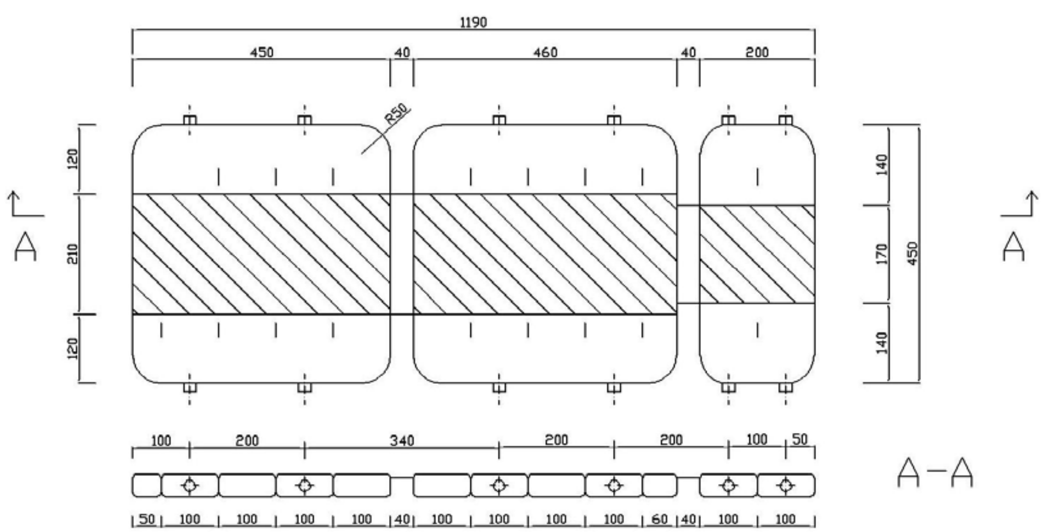



*Figure 5.1.1. Sketch of seat strap*

The area of seat strap cover almost all seat, however, we were using only top and middle part in our research.

It was made by KE Fibertec AS Company. The prototype consists of two different sections. Middle, which goes along all length in place covered by seating passenger, is made of impermeable material. Second is made of two special permeable materials (KE- material 025600– top of the seat strap and KE- material 025030– middle and bottom part). These sections are responsible for distributing fresh air to occupant's boundary layer. The downside part is made of impermeable textile (see Figure 5.1.2.).

*Figure 5.1.2. The front and the back side of the seat strap*

[1], [2], [5]

## 5.2. Seat Cover

Seat Cover has exactly the same shape and properties as seat strap. The only one difference is that the top part of this diffuser is made with permeable material on its whole surface (also on this part covered by seating passenger).

*Figure 5.2.1. The front and the back side of the seat cover*

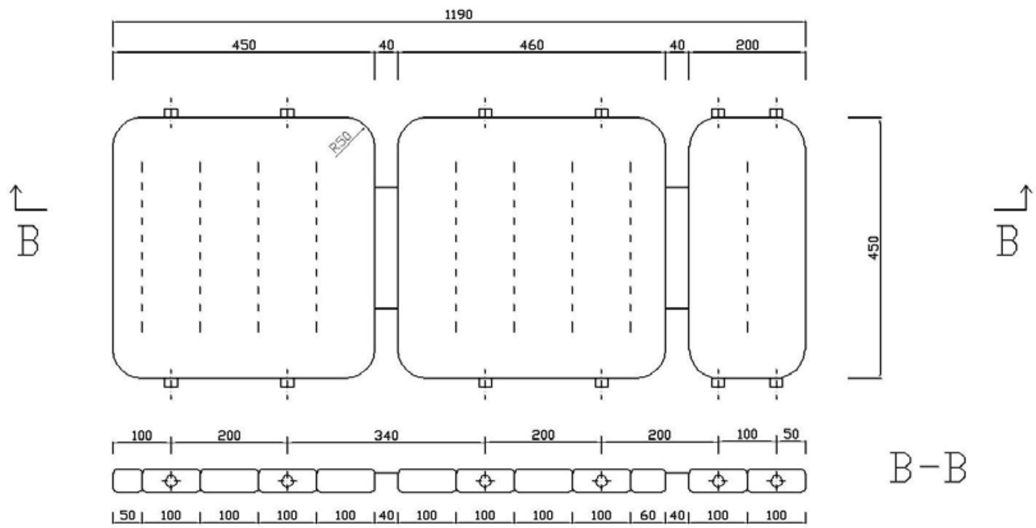



*Figure 5.2.2. Sketch of seat cover*

[5]

## *5.3. Angle Seat Cover*

This seat is also made by Ke Fibertec AS Company. It is originally design for this project. It consists of two materials to be able to have the correct pressures inside the seat. The top is made in KE-material 025030 and the bottom in KE-material 025020 (both with special Trevira CS fabric construction (HDC). [5]

Figure below show dimensions and shape of this seat cover

*Figure 5.3.1. Angle seat cover*

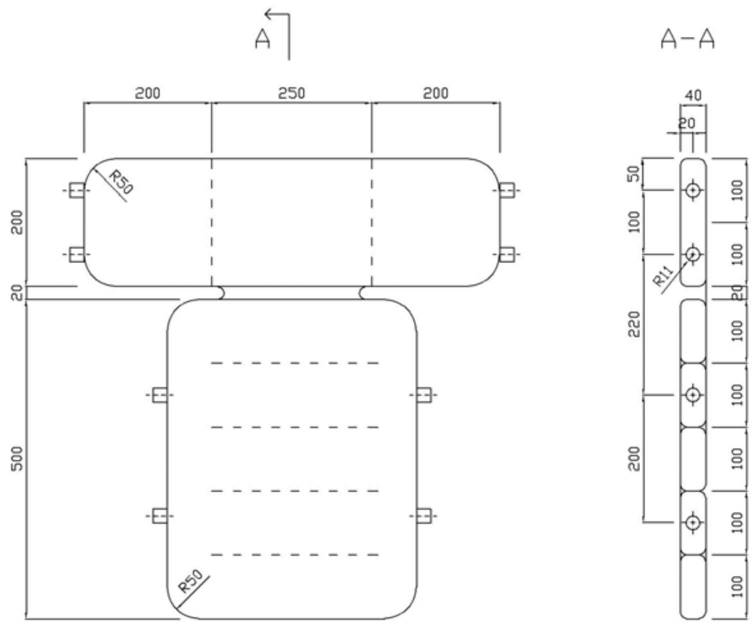



*Figure 5.3.2. Angle seat cover*

Top part, close to occupant's head, is wider than in previous diffusers. Thanks to that, we can make different angles (β) to achieve better effectiveness. However, in our research we consider β=45° (Figure 5.3.3.).

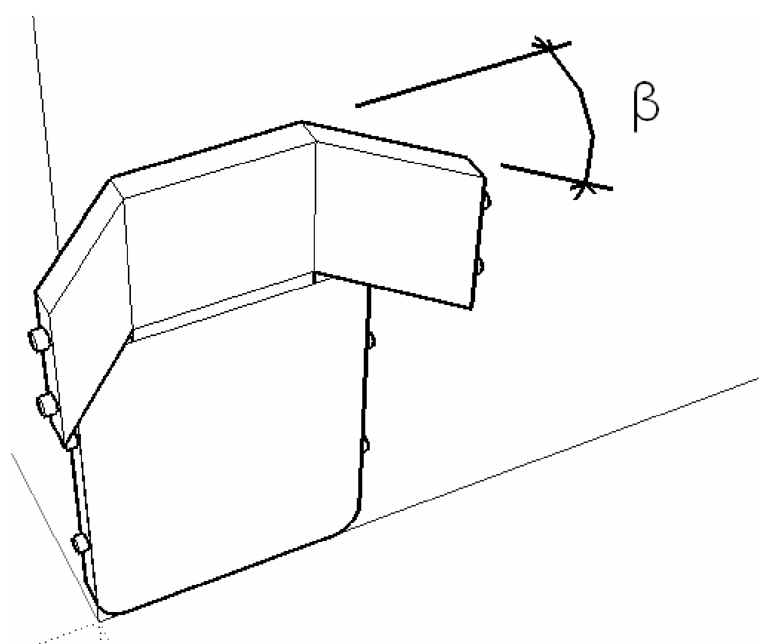



*Figure 5.3.3. Different angles of bending seat cover*

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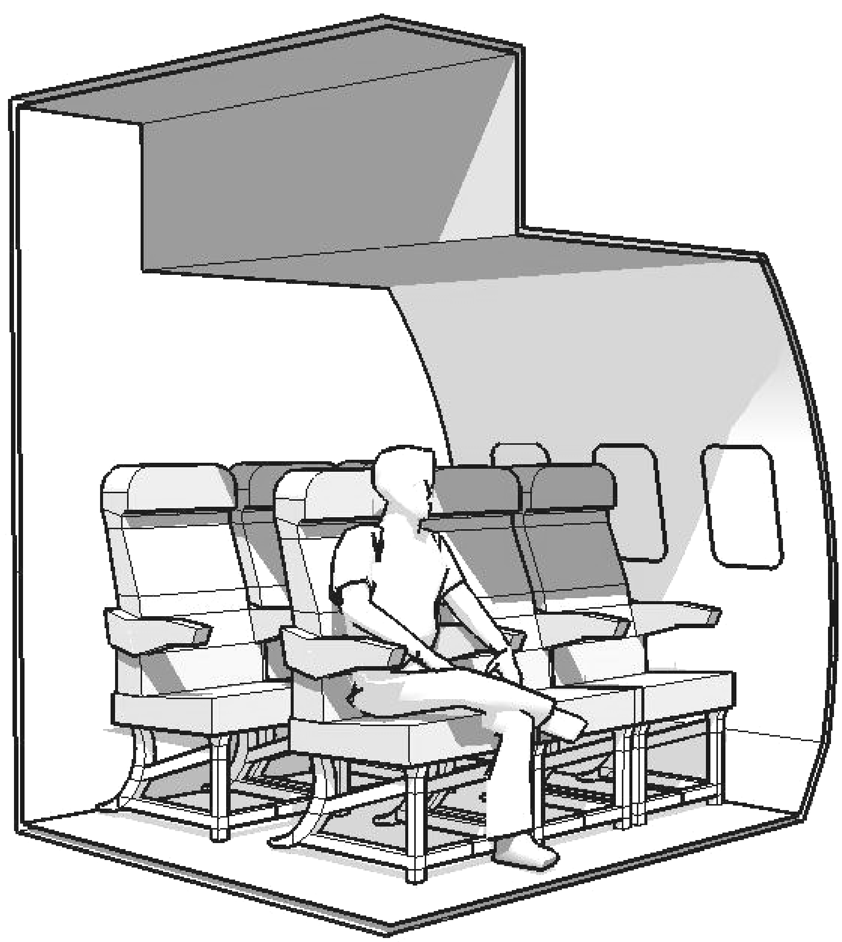
# 6.CHAPTER

# MEASUREMENTS



## *6.1 Tracer gas measurements*

### 6.1.1. Reference to tracer gas measurement

$N_2O$ (laughing gas) is used as a tracer gas. The concentration of this gas is measured to define effectiveness of personal ventilation system.

Gas Analyzer used in experiment to measure $N_2O$ concentration has 6 slots what means that concentration can be checked only in 6 different places. Each sample is analyzed for 60 seconds. So that one series of measurement for 6 samples takes 360 second (6 minutes). In the experiment 5 series of measurements are conducted in the wind tunnel and 10 series in the cabin section to obtain more precise results. Thus, full cycle for each airflow from the diffuser takes 30 or 60 minutes depending on number of series. Temperature and velocity in the model are measured simultaneously with gas concentration. Tracer gas is supplied to the diffuser in certain amount 0,02 l/s. In order to obtain it the pressure of N2O is adjusted on 1 bar.

All tubes used to measure gas concentration are connected to the Multipoint Sampler and Dozer type 1303. Thus, all the information are analyzed by Tracer Gas Monitoring Systems which is controlled by PC. Data are converted into a graphic form and tables, and saved on the PC.

### 6.1.2. Effectiveness of personal ventilation during experiment in the wind tunnel

In order to compare different setups of personalized ventilation (position of the aircraft seat, velocity in wind tunnel and flow rate from tested diffuser) effectiveness indexes are used.
Setup used during measurements in the wind tunnel is shown in Figure 6.1.1.

Concentration of tracer gas is measured in six locations:

1 - in the air inhaled by the manikin's mouths
2 - 60 cm in front of the manikin's head
3 - in the air supplied to the diffuser
4 - in the exhaust pipe
5 - in the air outside the wind tunnel (in the laboratory)
6 - near the tracer gas bottle

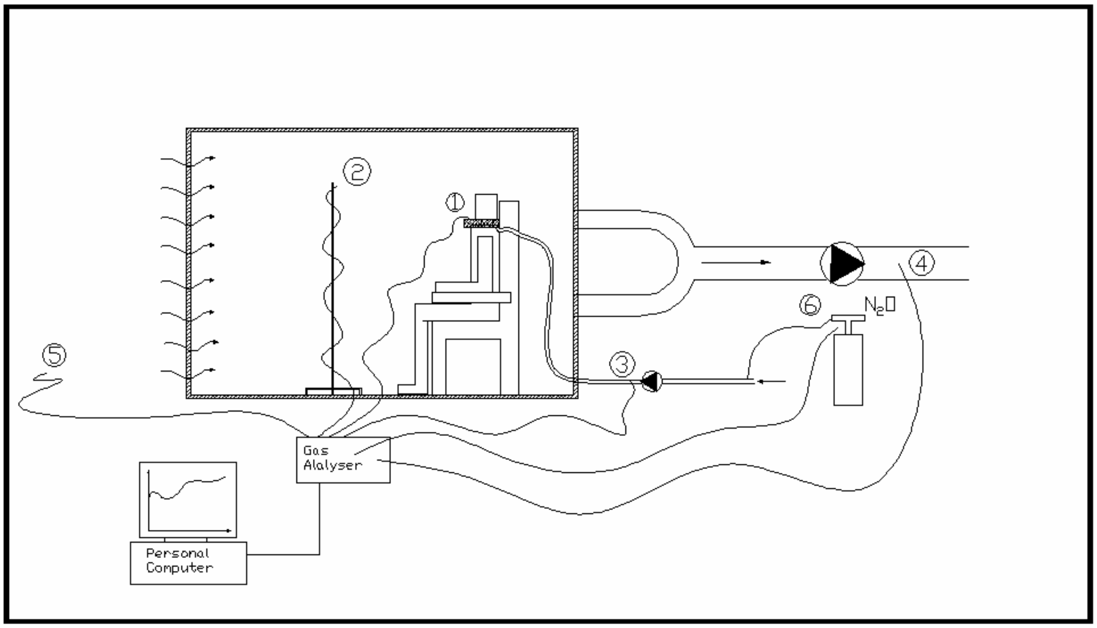



*Figure 6.1.1. Scheme of location the tracer gas tubes in the wind tunnel [1]*

Supply air to the wind tunnel is drawn from laboratory through permeable wall. Thus, the air in the wind tunnel is physically the same as this from laboratory. Due to this fact it is uneconomical and at least hazardous from healthcare point of view to fill whole wind tunnel (what means to fill laboratory as well) with tracer gas because safety level of N2O for people is 25 ppm. Furthermore, it would be also hard to keep a steady concentration level of tracer gas.

Due to above mentioned technical aspects the wind tunnel is supplied by clean air and personal ventilation diffuser is supplied by the mixture of tracer gas and fresh air. So that the following formula is used to express the effectiveness in the wind tunnel: [1]

$$\varepsilon_{PV} = \frac{c_{\exp,PV} - c_{lab}}{c_{PV} - c_{lab}} \cdot 100\% \qquad [6.1]$$

where:

$\varepsilon_{PV}$ – effectiveness of personal ventilation in wind tunnel [%]
$c_{exp,PV}$ – contaminant concentration in the inhaled air (manikin's nose) [ppm]
$c_{exp,lab}$ – contaminant concentration in the laboratory [ppm]
$c_{PV}$ – contaminant concentration in the supply pipe from the PV diffuser [ppm]

### 6.1.3. General ventilation index during experiment with personal ventilation diffuser in the cabin section

During measurements in the cabin section model the following setup is used:

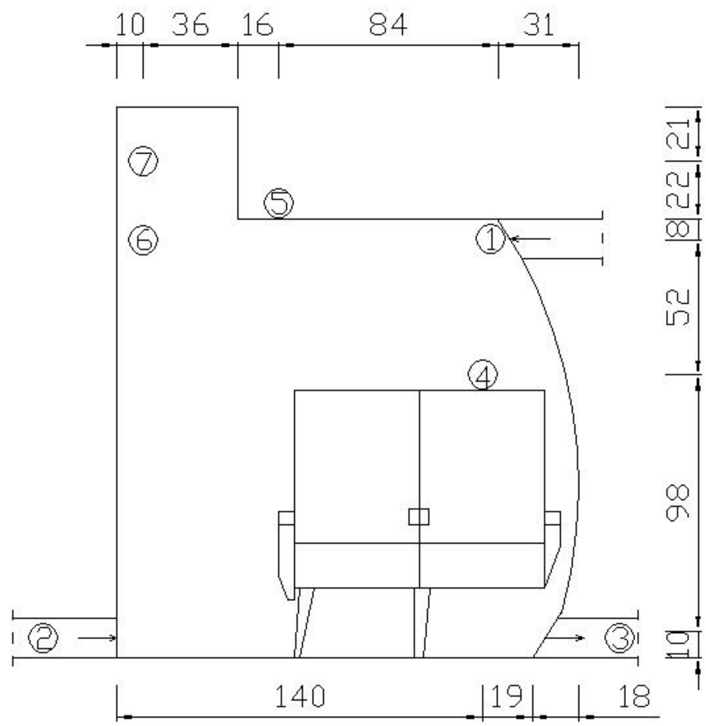



*Figure 6.1.2. Scheme of location the tracer gas tubes in the cabin section*

Concentration of tracer gas is measured in the following representative locations:

1 – in air nozzle below the ceiling
2 – in personal ventilation supply pipe
3 – in return pipe outside the model
4 – in the air inhaled by the Monkey's nose
5 – in the air outside the cabin section (in the laboratory)
6 – 160 cm above the floor
7 – 190 cm above the floor

In cabin section model different setup is investigated than it is presented in the wind tunnel. Instead of one, two manikins are used in this case. Comfortina (see Appendix B.5.1.) as a source and Monkey (see Appendix B.5.2.) as a receiver. Comfortina exhales tracer gas and other manikin inhales it. Thus, this setup allows to measure impact of one passenger to other. In experiment with personal ventilation system, new conception of diffuser is used (see Chapter 5.3.). Cabin section is classified as a small room so that it is not possible to count the effectiveness of personal ventilation (PV influence the general distribution system). Due to this fact ventilation index for PV and general system is used.

$$\varepsilon_{\exp,system} = \frac{c_R - c_0}{c_{\exp,PV} - c_0} \cdot 100\% \qquad [6.2]$$

where:
εexp,system – ventilation index for PV and general system [%]
$c_R$ – contaminant concentration in exhaust pipe [ppm]
c0 – contaminant concentration in supply air nozzle [ppm]
$c_{exp,PV}$ – contaminant concentration in the inhaled air (Monkey's nose) [ppm]

### 6.1.4. Ventilation index and air quality index during experiment in the cabin section

Ventilation index presents how many times inhaled air by the manikin is cleaner than the surrounding air. In case of mixing or displacement ventilation system the following formula is used to express ventilation index.

$$\varepsilon_p = \frac{c_R - c_0}{c_{\exp} - c_0} \qquad [-] \qquad [6.4]$$

where:
$\varepsilon_p$ – ventilation index [-]
$c_R$ – contaminant concentration in exhaust pipe [ppm]
$c_0$ – contaminant concentration in supply air nozzle [ppm]
$c_{exp}$ – contaminant concentration in the inhaled air (Monkey's nose) [ppm]

Additionally, for description air quality in the occupied zone air quality index is counted.

$$\varepsilon_{oz} = \frac{c_R - c_0}{c_{oz} - c_0} \qquad [-] \qquad [6.5]$$

where:
$\varepsilon_{oz}$ – air quality index [-]
$c_R$ – contaminant concentration in exhaust pipe [ppm]
c0 – contaminant concentration in supply air nozzle [ppm]
$c_{oz}$ – contaminant concentration in the occupied zone (in the corridor, stewardess' head level) [ppm]

Contaminant concentration in the occupied zone coz is counted as an average from two representative points which are located in the corridor 160 cm and 190 cm above the floor. Heights of these sensors are chosen to count the average concentration in the point where passenger's or stewardess's head suppose to be during walking along the corridor.

## *6.2. Velocity and airflow measurements*

### 6.2.1. Reference to airflow measurements

Airflow supplied from personal ventilation diffuser varies from 16 l/s to 2 l/s and it bases on pressure drop on the orifice that can be counted from following formula:

$$\Delta p = 0{,}00998071 \cdot q_v^{2{,}04977} \quad \text{[mbar]} \qquad [6.6]$$

Return air stream in cabin section model is set accordingly to pressure drop on the orifice in the exhaust pipe before the fan. Pressure drop is read from graph written on this orifice (see Appendix B.6.3.).

Supply air is adjusted to personal ventilation and return air. Pressure difference between inside and outside the model is set to zero. That means the same volume of supply air is coming into the model as coming out of it.

### 6.2.2. Velocity measurements during experiments in the wind tunnel

Velocity measurement is carried out to check the value of local velocity near manikin's head. According to thermal comfort, velocity should not be higher than 0.20 m/s because of drought feeling.
In this experiment velocity is measured 60 cm in front of manikins face. The anemometer is situated in the centre of wind tunnel in crosswise section (see Figure 6.2.1. and 6.2.2.).

Velocity in the wind tunnel is set up according to anemometer's indications. Furthermore it is set up when personal ventilation system is disable to be sure that airflow from PV diffuser will not influence the results from anemometer. The main assumption for velocity in this experiment is to set up 0,05 m/s and 0,1 m/s in front of manikin face. However, due to unstable conditions in the model sometimes it is impossible to get these values. This problem is described in Chapter 7.1.1.

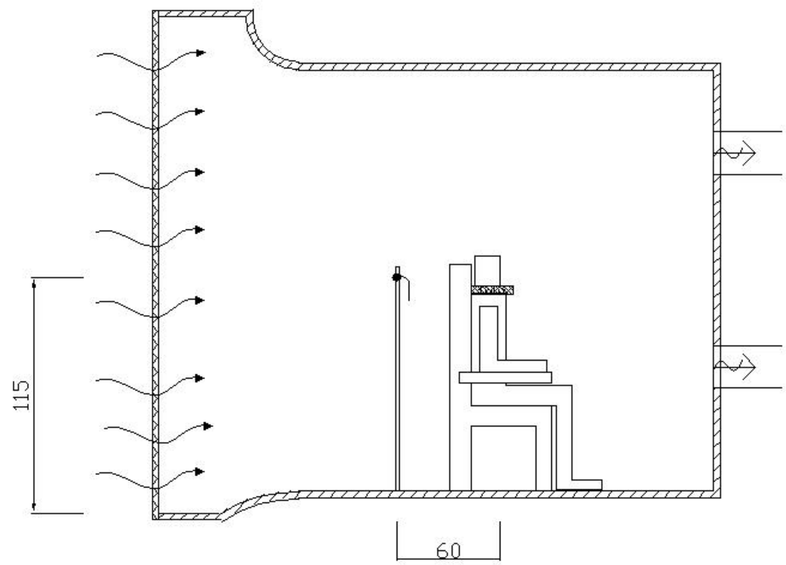



*Figure 6.2.1. Laboratory lengthwise section with anemometer in the wind tunnel*

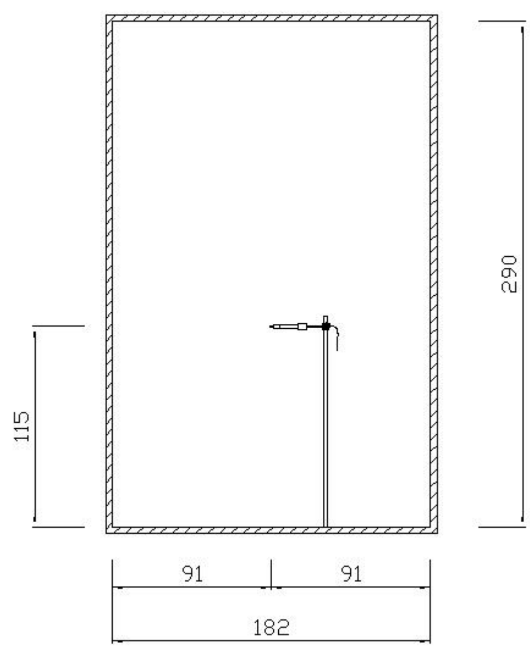



*Figure 6.2.2. Laboratory crosswise section with anemometer in the wind tunnel*

### 6.2.3. Velocity measurement during experiment in the cabin section model

During experiments in the cabin section velocity should be measure in point where velocity value is maximal. Thus, velocity distribution is made out base on empirical results. Figure 6.2.6. shows velocity distribution in case of mixing ventilation.

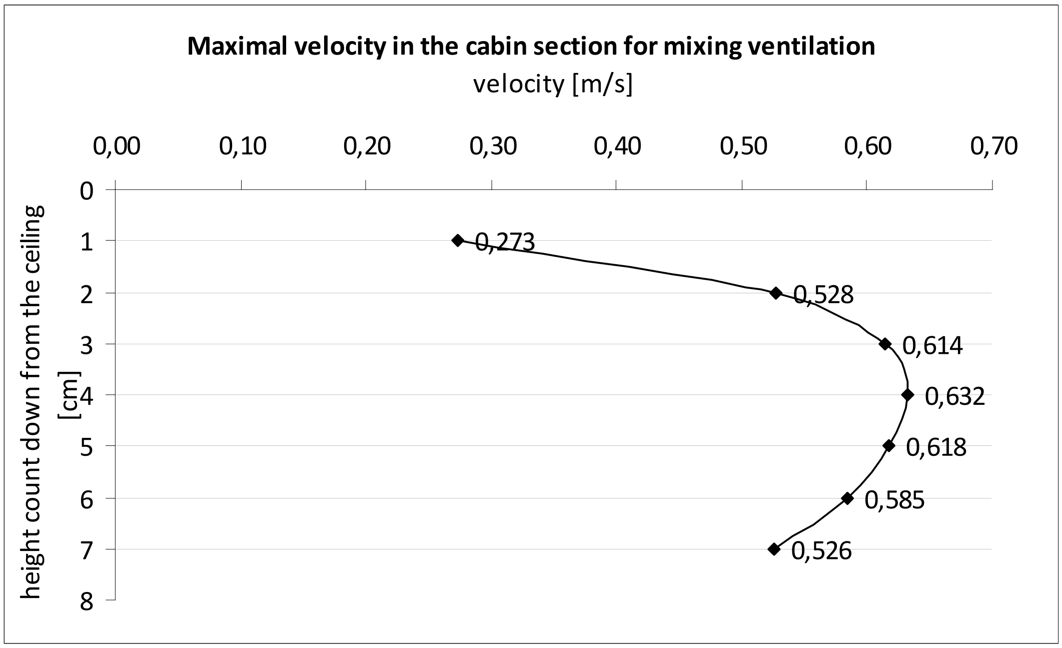



*Figure 6.2.6. Velocity distribution in the cabin section in case of mixing ventilation*

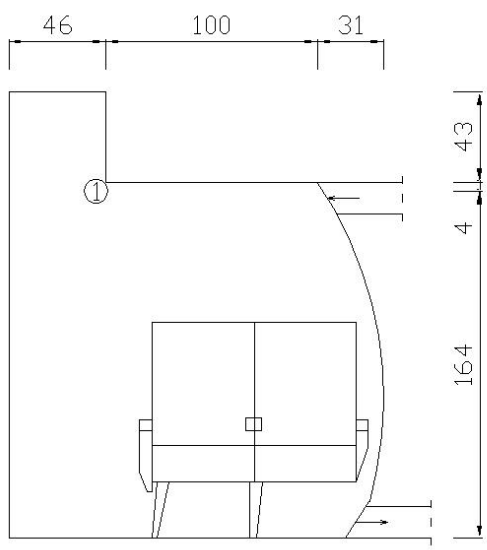



*Figure 6.2.7. Laboratory lengthwise section with anemometer in the cabin section*

In further measurements for mixing ventilation and/or personal ventilation velocity is measured 4 cm below the ceiling to have a view on maximal speed in cabin section cabin. In case of displacement ventilation and its combination with PV maximal velocity appears in the supply lower nozzle. According to thermal comfort velocity value should not be higher than 0.20 m/s because of drought feeling.

### 6.2.4. Velocity integration time

Velocity integration time is a period in which the mean value of velocity becomes stable. As long as the experiments are done in wind tunnel, velocity integration time is taken from report "New Solution for Personalized Ventilation in Aircrafts. Textile Ventilating Surfaces" [1] and it equals 5 minutes.
In order to find integration time for experiments in cabin section, the sensor exposed to the greatest turbulences measures mean velocity for 0.20 m/s. Measurements are repeated 10 times for the following periods:

- 0.5 min
- 1 min
- 3 min
- 5 min
- 7 min
- 10 min

| Measurement No. | 0,5 min | 1 min | 3 min | 5 min | 7 min | 10 min |
|---|---|---|---|---|---|---|
| | [m/s] | | | | | |
| 1 | 0,592 | 0,616 | 0,649 | 0,628 | 0,628 | 0,64 |
| 2 | 0,633 | 0,635 | 0,644 | 0,636 | 0,638 | 0,642 |
| 3 | 0,624 | 0,633 | 0,63 | 0,637 | 0,636 | 0,633 |
| 4 | 0,598 | 0,637 | 0,631 | 0,633 | 0,632 | 0,644 |
| 5 | 0,615 | 0,649 | 0,637 | 0,629 | 0,642 | 0,642 |
| 6 | 0,619 | 0,643 | 0,635 | 0,627 | 0,64 | 0,639 |
| 7 | 0,632 | 0,644 | 0,637 | 0,634 | 0,638 | 0,634 |
| 8 | 0,645 | 0,635 | 0,623 | 0,631 | 0,64 | 0,642 |
| 9 | 0,611 | 0,624 | 0,633 | 0,639 | 0,653 | 0,643 |
| 10 | 0,616 | 0,643 | 0,636 | 0,637 | 0,647 | 0,639 |

*Table 6.2.2. Velocity integration time measurement data*

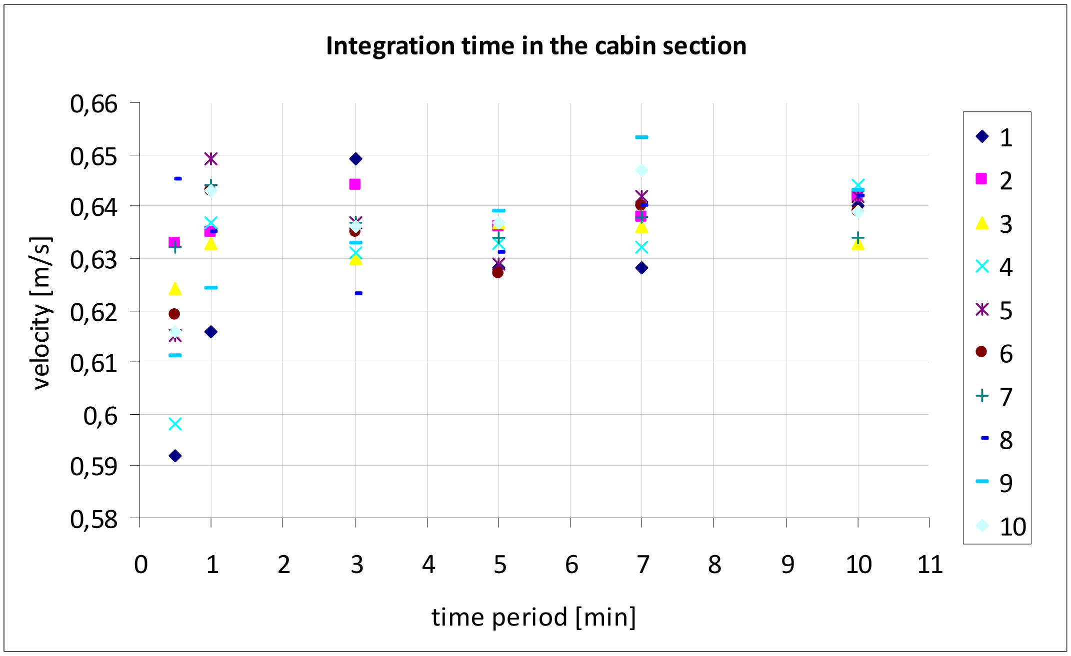



*Figure 6.2.8. Velocity integration time measurement data*

Figure 6.2.8. shows that integration time of less than 1 minute is insufficient to obtain steady velocity value. It might be caused by the airflow turbulences generated by both manikins. It is noticeable that in the course of time velocity values become stable. However, it is possible that to long time period causes some dispersion of mean velocity value because temperature changes in the cabin section.
Due to above reasons 5 minutes is chosen as an integration time as accurate time to minimize influence of turbulence and temperature changes.

## *6.3. Temperature measurements*

### 6.3.1. Reference to temperature measurements

K - type thermocouples are used to measure temperature in the models. Measurements are carried out simultaneously to concentration and velocity measurements. Temperature is measured during 30 minutes cycle for each airflow from the diffuser in wind tunnel and during 60 minutes cycle for each airflow from the diffuser in the cabin section.

### 6.3.2. Temperature measurements during experiment in wind tunnel

During this experiment, temperature is measured to obtain temperature changes inside personal ventilation diffuser as well as temperature differences between temperature of supply air from PV diffuser and in the wind tunnel.

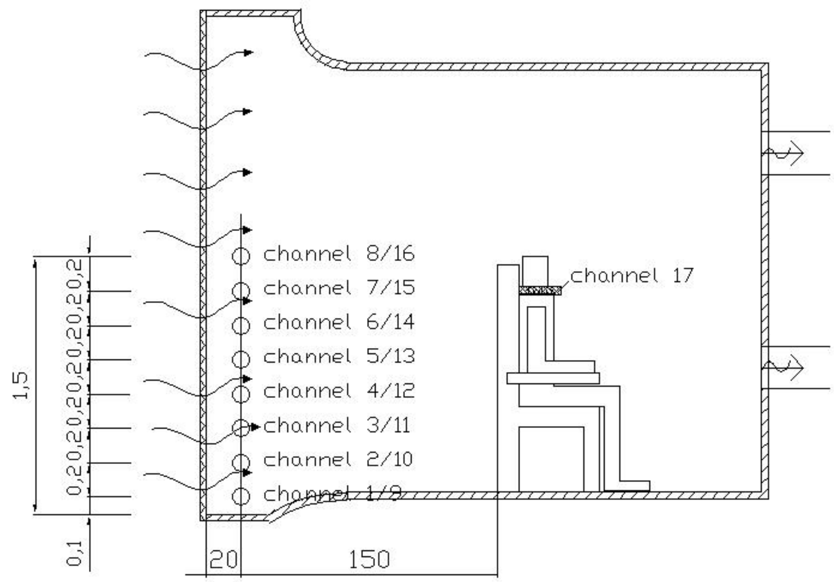



*Figure 6.3.1. Laboratory lengthwise section with thermocouples in wind tunnel*

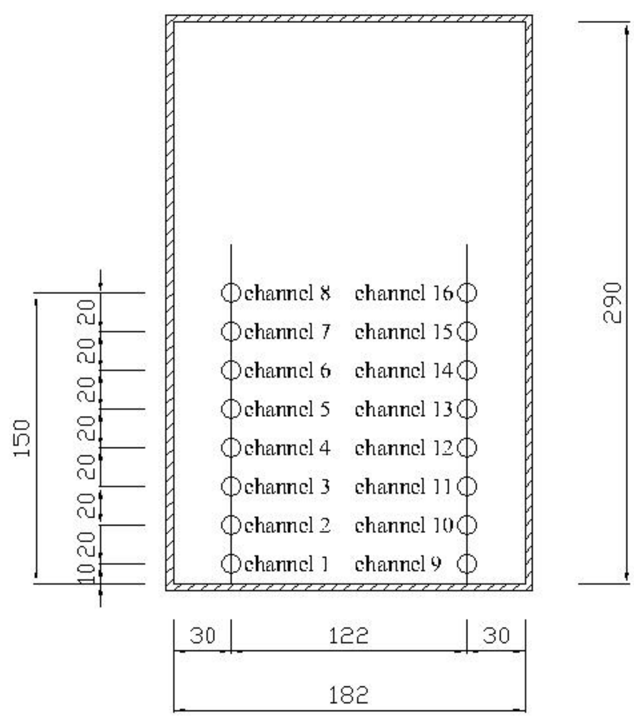



*Figure 6.3.2. Laboratory crosswise section with thermocouples in wind tunnel*

Temperature is measured by 16 thermocouples situated 150 cm behind the aircraft seat which are evenly located in two parallel columns start from 0.1 m over the floor and rise for every 0.2 m. Beside it there is used 1 thermocouple situated inside the diffuser, as it is shown in Figure 6.3.1. and Figure 6.3.2.

### 6.3.3. Temperature measurements during experiments in the cabin section

During experiment in the cabin section cabin, temperature is measured in 10 locations to adjust temperature and obtain vertical temperature distribution inside the cabin. It is especially useful during experiments with displacement ventilation. Beside it temperature inside both diffusers is measured to see the temperature of supplying air from the PV diffuser.

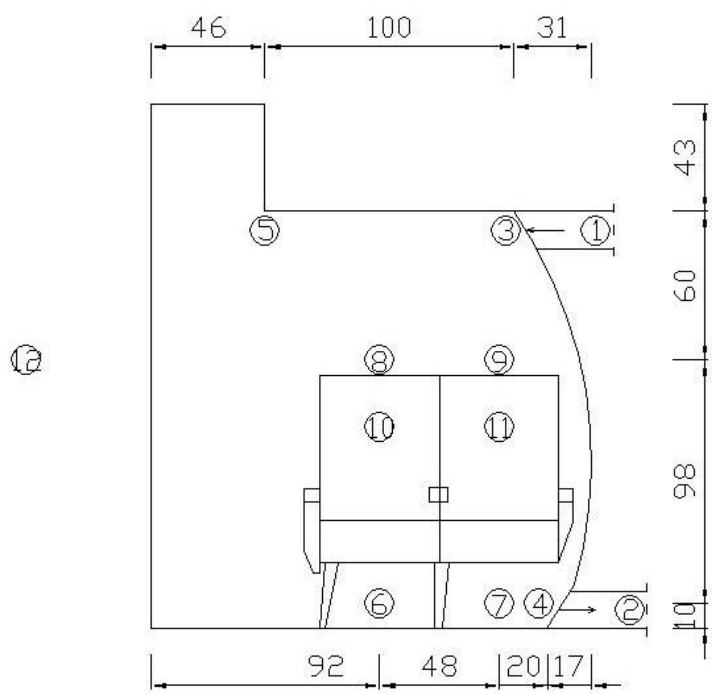



*Figure 6.3.3. Laboratory crosswise section with thermocouples in cabin section*

Temperature is measured in eleven locations what is shown in Figure 6.3.3.

1 – in supply pipe outside the model
2 – in return pipe outside the model
3 – in air nozzle below the ceiling
4 – in air nozzle above the floor
5 – on the anemometer
6 – 10 cm above the floor in front of Comfortina

7 – 10 cm above the floor in front of Monkey
8 – 60 cm in front of Comfortina's head
9 – 60 cm in front of Monkey's head
10 – inside Comfortina's diffuser
11 – inside Monkey's diffuser
12 – in the laboratory

Temperature in the cabin section should be constantly 23°C. Two manikins are set to give up 80 W each to the surroundings. Thus, the temperature of supply air is counted from the following formula:

$$\Delta T = \frac{Q}{c_p \cdot \rho \cdot q} \qquad [6.6]$$

where:
ΔT – temperature difference between inside (Ti) and supply air (Ts) [K]
$c_p$ – specific heat [J/kg·K]
ρ– density of inside air [kg/m3]
Q – inside heat flux [W]

Furthermore following assumption are made:
ΔT = Ti – Ts
$T_i$ = 23°C
$c_p$ = 1005 [J/kg·K]
ρ = 1,29 [kg/m3]
Q = 80 + 80 = 160 [W]

## 6.4. Smoke simulation

Smoke simulation is made in order to visualize how tested personal diffuser works, what is happening in reality with the air coming out of it. Thanks to smoke supplied to the diffuser simultaneously with fresh air, it is possible to check directions of airflow, how much air can get to the manikin's breathing zone and how much gets to the sides.

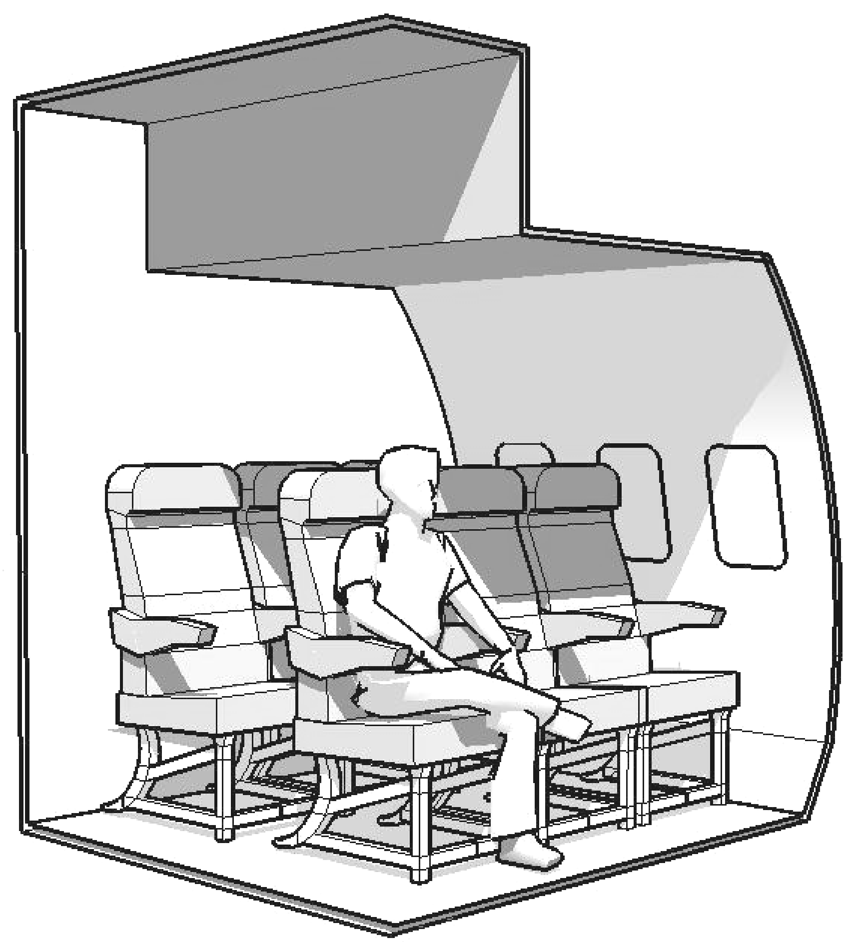
In order to conduct smoke simulation, special oil - based smoke machine is connected to the pipe which supplies the diffuser with fresh air (see Appendix C.7.). In a device there is a bottle of liquid which under the influence of temperature is changing its state of matter into gaseous form. Remote control unit uses to regulate the temperature helps to obtain required amount of smoke coming out of the diffuser. Smoke used in experiments is non - toxic and safe to use.

### *Bibliography:*


- [1] E. Barszcz, T. Czarnota, D. Dymalski, M. Jasieński, A. Mozer, A. Nowotka, S. Wiankowska "New Solution for Personalized Ventilation in Aircrafts. Textile Ventilating Surfaces". Aalborg University 2007

# 7.CHAPTER

# RESULTS



## *7.1. Results for measurements in wind tunnel*

### 7.1.1. Problems occurred during measurements in the wind tunnel

In case of measurements for small velocities inside the wind tunnel it is noticed that this model with its volume 11,43 m3 corresponds to small room. Thus, if N2O is blown out from personal ventilation diffuser, whole wind tunnel is filled by tracer gas. This situation is the most visible when, beside low velocity in the wind tunnel, high airflow is supplied from the PV diffuser.

To prove that, example of results for tracer gas concentration within the wind tunnel is shown in Table 7.1.1. and Figure 7.1.1. below. Concentration results refer to top part of seat cover when aircraft seat is set in position 0°.

| *Velocity in the wind tunnel 0,04 m/s* | | | |
|---|---|---|---|
| *Airflow from PV diffuser* | *Concentration in supply from PV diffuser* | *Concentration near permeable wall* | *Percent of air coming to permeable wall* |
| [l/s] | [ppm] | | [%] |
| 15 | 88,73 | 35,75 | 40 |
| 14 | 95,88 | 41,92 | 44 |
| 12 | 116,23 | 47,83 | 41 |
| 10 | 132,78 | 40,35 | 30 |
| 8 | 171,04 | 40,00 | 23 |
| 6 | 210,60 | 69,69 | 33 |
| 4 | 308,47 | 8,42 | 3 |
| 2 | 600,60 | 7,66 | 1 |

*Table 7.1.1. Concentration results within the wind tunnel*

Thanks to tracer gas tube located near permeable wall, 150 cm above the floor, it is possible to know horizontal distribution of tracer gas inside the model. Values from Table 7.1.1. prove that tracer gas moves towards permeable wall instead of being vented through exhaust pipe. This problem occurs always when balance between airflow from PV and velocity in the wind tunnel is exceeded because exhaust pipe is not able to blow whole supplying air out of the model

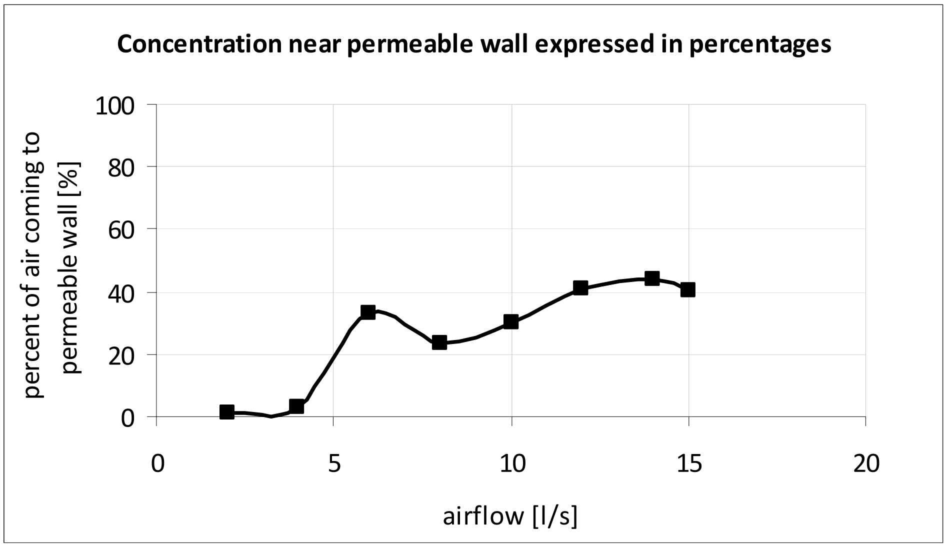



*Figure 7.1.1. Concentration near permeable wall expressed in percentages*

It is noteworthy that air, which moves against the main stream, generates instability of airflow in the wind tunnel. In addition, effectiveness of personal ventilation system can be only counted for large room or eventually in wind tunnel if small concentration near permeable wall is noted, what is obtained for high velocity in the wind tunnel and low airflow from PV diffuser.

To prove instability of airflow inside the wind tunnel the investigation is made on the basis of both diffusers: seat cover and seat strap, for the same airflow from each diffuser equaled 2 l/s. The airplane seat is set in 180° and pressure drop on the orifice in the exhaust pipe before the fan is constantly 0,055 mbar.

For investigation needs, three anemometers are set. One near permeable wall, another 10 cm in front of lower exhaust pipe and the last one behind manikin’s face. The values from these points are useful for lengthwise velocity distribution.

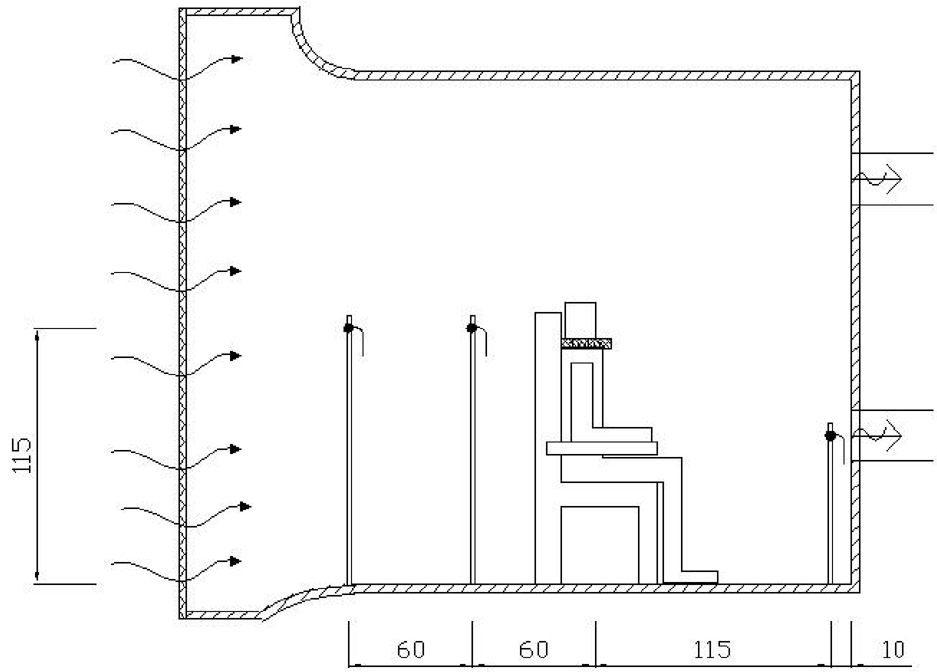



*Figure 7.1.2. Laboratory lengthwise section with 3 anemometers in the wind tunnel*

Table below shows results for 3 anemometers for the same pressure drop and the same airflow from different diffusers. Instability of airflow is visible comparing values from the same point of the same parts of different diffusers.

| *pressure 0,055 [mbar]* | | | | | | |
|---|---|---|---|---|---|---|
| *airflow 2 [dm3/s]* | | | | | | |
| *parts of diffuser* | *seat strap* | | | *seat cover* | | |
| | *point no.1* | *point no.2* | *point no.3* | *point no.1* | *point no.2* | *point no.3* |
| top | 0,085 | 0,141 | 0,379 | 0,09 | 0,13 | 0,348 |
| both | 0,088 | 0,096 | 0,351 | 0,078 | 0,121 | 0,337 |

*Table 7.1.2. Velocity measurements providing instability of airflow in the wind tunnel [m/s]*

where:
point no.1 – near permeable wall
point no.2 – behind manikin's face
point no.3 – 10 cm in front of lower exhaust pipe

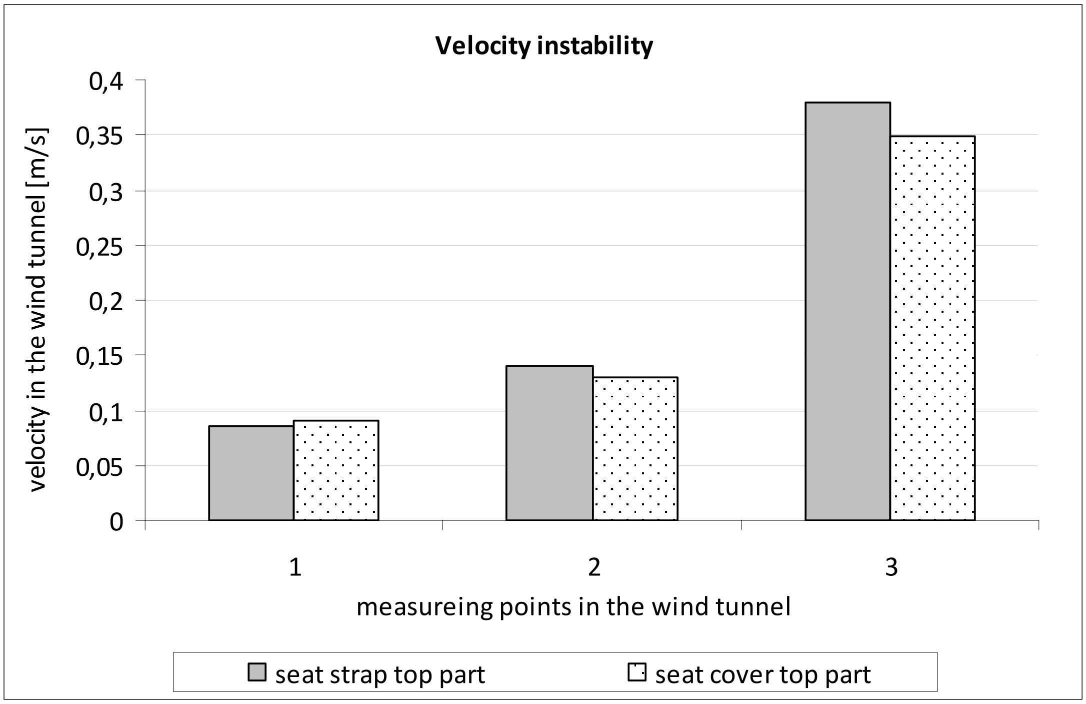



*Figure 7.1.3. Example for velocity instability for top part of tested diffusers*

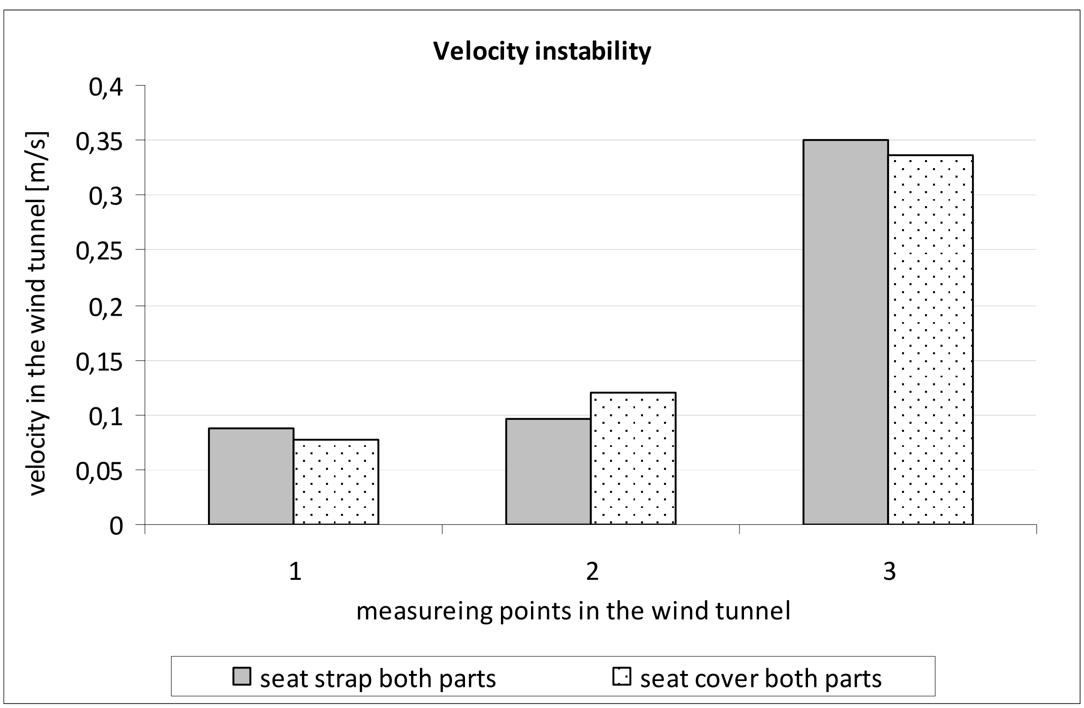



*Figure 7.1.4. Example of velocity instability for both parts of tested diffusers*

### 7.1.2. Seat strap diffuser top part, seat position 0°

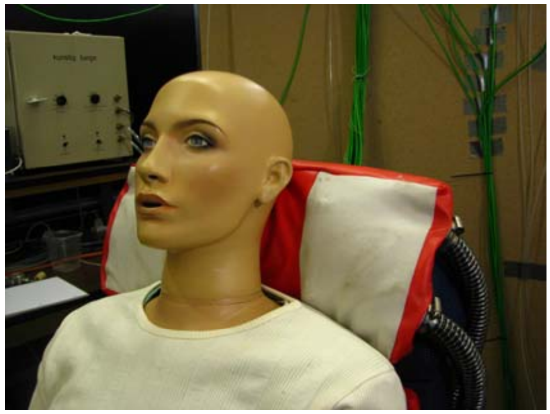


*Figure 7.1.5. Seat strap diffuser top part*

Measurements results of personalized ventilation effectiveness for aircraft seat placed in 0° position, with breathing function are presented below:

| *Seat strap diffuser top part* | | |
|---|---|---|
| *Airflow [l/s]* | *Effectiveness [%]* | |
| | *0,04 m/s* | *0,1 m/s* |
| 2 | 1,97 | 0,00 |
| 4 | 5,01 | 0,02 |
| 6 | 7,78 | 1,55 |
| 8 | 22,40 | 7,53 |
| 10 | 44,33 | 13,98 |
| 12 | 49,04 | 6,80 |
| 14 | 38,51 | 2,49 |
| 16 | 64,27 | 7,97 |

*Table 7.1.3. Tracer gas measurements results for seat strap diffuser top part*

Top part of seat strap diffuser is tested for two velocities, each for seat in position 0°. Results for velocity 0,04 m/s in the wind tunnel marked on grey are connected with problem described in Chapter 7.1.1.

Thus, only effectiveness for velocity 0,1 m/s in the wind tunnel is surely right. However, as it is shown in the Figure 7.1.6., maximal effectiveness doesn't reach 20%. Despite the fact that effectiveness for 0,04 m/s does not fully refer to reality, it provides very low effectiveness in comparison with results from previous semester.

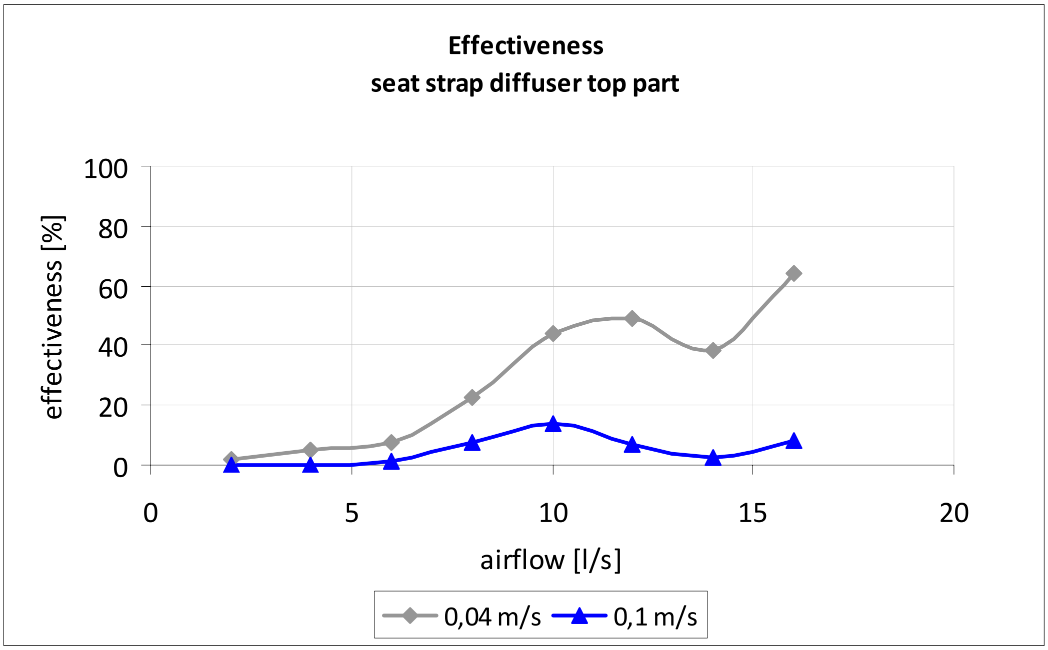



*Figure 7.1.6. Effectiveness graph for seat strap diffuser top part, seat position 0°*

### 7.1.3. Seat cover diffuser top part, seat position 0°

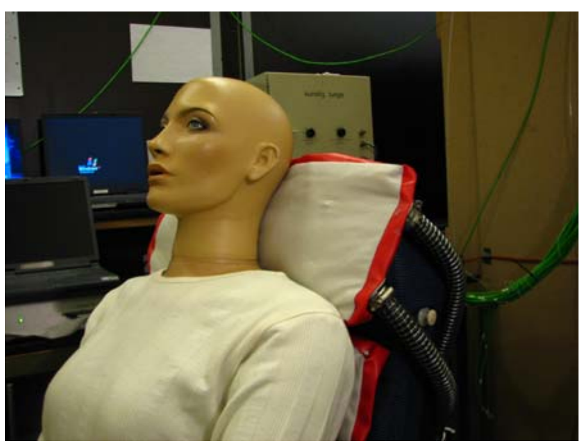


*Figure 7.1.7. Seat cover diffuser top part*

Measurements results of personalized ventilation effectiveness for aircraft seat placed in 0° position, with breathing function are presented below:

| Seat cover diffuser top part | | | |
|---|---|---|---|
| *Airflow [l/s]* | *Effectiveness [%]* | | |
| | *0,04 m/s* | *0,06 m/s* | *0,1 m/s* |
| 2 | 25,99 | 0,41 | 0,24 |
| 4 | 54,56 | 6,30 | 3,05 |
| 6 | 11,94 | 30,64 | 8,50 |
| 8 | 18,59 | 32,57 | 8,38 |
| 10 | 55,52 | 72,82 | 9,78 |
| 12 | 52,64 | 70,27 | 25,21 |
| 14 | 78,18 | 76,73 | 52,28 |
| 15 | 78,95 | 65,56 | 50,02 |

*Table 7.1.4. Tracer gas measurements results for seat cover diffuser top part*

Top part of seat cover diffuser is tested for three velocities, each for seat position 0°. However, effectiveness values for velocity 0,04 m/s and 0,06 m/s in the wind tunnel can be lower in reality because they are connected with problem described in Chapter 7.1.1. Grey line is used to mark inaccurately effectiveness values.

Results for velocity 0,06 m/s in the wind tunnel are correct only for very small airflow from PV diffuser and effectiveness in these cases is as low as the airflow. This setup is useful only when velocity in the wind tunnel is set to 0,1 m/s. Then the highest effectiveness is observed for 14 l/s from top part of seat cover diffuser. However, it is still only 52%.

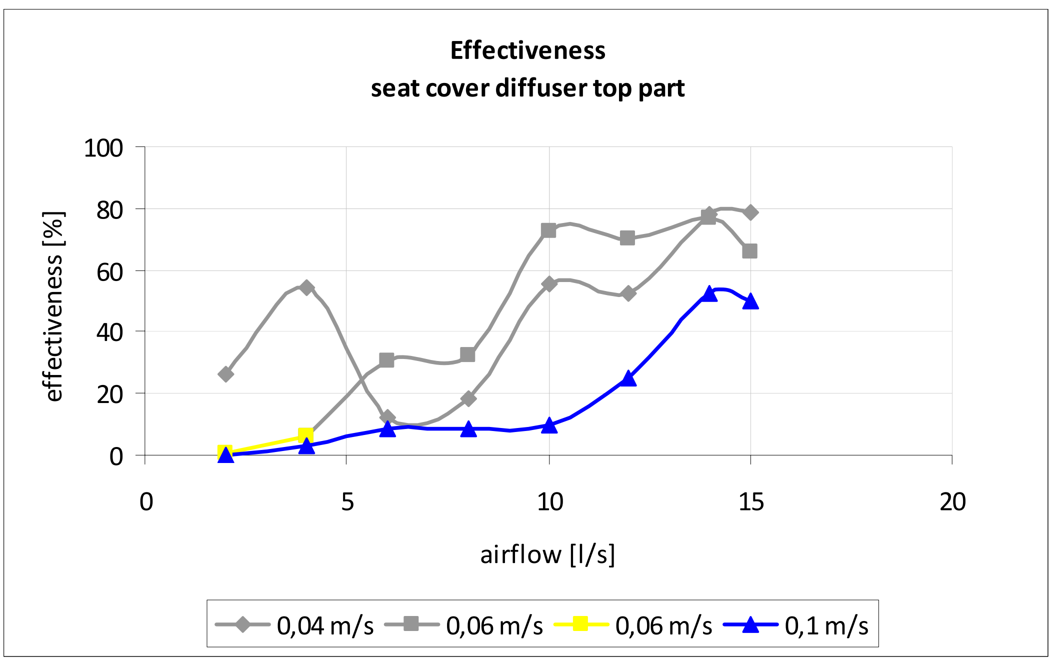



*Figure 7.1.8. Effectiveness graph for seat cover diffuser top part, seat position 0°*

There is no point to predict real effectiveness values for velocity 0,04 m/s or 0,06 m/s because they will not be higher than their incorrect equivalents.

### 7.1.4. Seat strap diffuser top part, angle 45°, seat position 180°

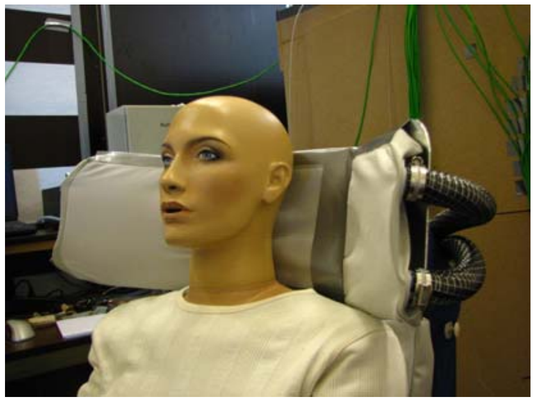


*Figure 7.1.9. Seat strap diffuser top part, angle 45°*

To optimize personal ventilation diffuser investigations within the range of airflow directivity are made. It is decided to change the position of aircraft seat from 0° to 180° because this setup is described in 9th semester project "New Solution For Personalized Ventilation in Aircrafts" as the best position. [1]
Than airflow supplied from top part of seat strap diffuser is changed from 0° to 45°.

Measurements results of personalized ventilation effectiveness for aircraft seat placed in 180° position, with breathing function are presented below:

| *Seat strap diffuser top part, angle 45°* | | |
|---|---|---|
| *Airflow [l/s]* | *Effectiveness [%]* | |
| | *0,03 m/s* | *0,12 m/s* |
| 2 | 16,35 | 8,98 |
| 4 | 54,99 | 49,92 |
| 6 | 73,73 | 85,60 |
| 8 | 91,70 | 94,77 |
| 10 | 97,19 | 94,64 |
| 12 | 93,79 | 94,99 |
| 14 | 91,90 | 96,44 |
| 16 | 89,03 | 92,80 |

*Table 7.1.5. Tracer gas measurements results for seat strap diffuser top part, angle 45°*

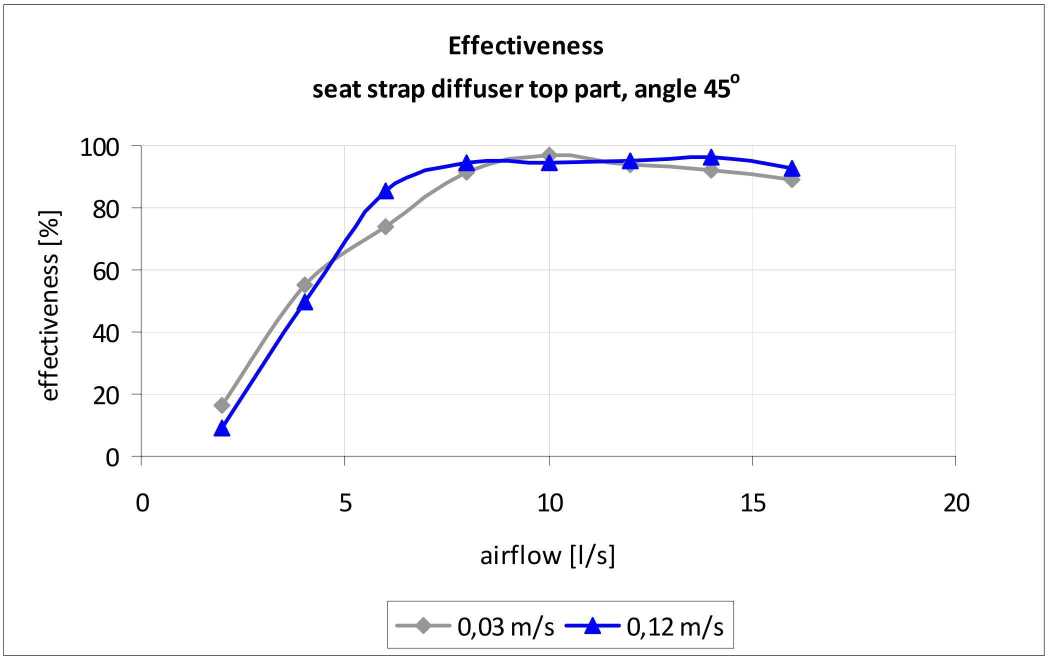



*Figure 7.1.10. Effectiveness graph for seat strap diffuser top part, angle 45° seat `*

To compare results, PV diffuser is tried to be tested for the same velocities as previously. However, due to velocity instability (see Chapter 7.1.1.) sometimes it is impossible to obtain the same values. Results for velocity 0,03 m/s in the wind tunnel are marked on grey because they are connected with problem described in Chapter 7.1.1. and they are not taken into consideration in this model.
Clear correlation between effectiveness, airflow and velocity is apparent in Figure 7.1.10. For velocity 0,12 m/s in the wind tunnel, effectiveness rises up very quickly till it reaches 8 l/s. Then it varies around 94%.

### 7.1.5. Seat strap diffuser both parts, angle 45°, seat position 180°

*Figure 7.1.11. Seat strap diffuser top plus middle part, angle 45°*

Measurements results of personalized ventilation effectiveness for aircraft seat placed in 180° position, with breathing function are presented in Table 7.1.6. Moreover, airflow is supplied from both parts of seat strap diffuser at an angle of 45°.

| *Seat strap diffuser top plus middle part, angle 45°* | | |
|---|---|---|
| *Airflow [l/s]* | *Effectiveness [%]* | |
| | *0,07 m/s* | *0,1 m/s* |
| 2 | 10,54 | 16,70 |
| 4 | 39,94 | 25,03 |
| 6 | 60,57 | 46,67 |
| 8 | 84,43 | 63,01 |
| 10 | 85,50 | 69,53 |
| 12 | 91,30 | 80,11 |
| 14 | 95,03 | 92,58 |
| 16 | 90,76 | 91,17 |

*Table 7.1.6. Tracer gas measurements results for seat strap diffuser top plus middle part*

Both parts of seat strap diffuser are tested for two velocities, each for seat position 180°. However, effectiveness values for velocity 0,07 m/s in the wind tunnel can be lower in reality because they are connected with problem described in Chapter 7.1.1. Grey line is used to mark inaccurately effectiveness values. However, high results without any errors appear for 14 l/s and 16 l/s from PV diffuser. They vary around 92%.

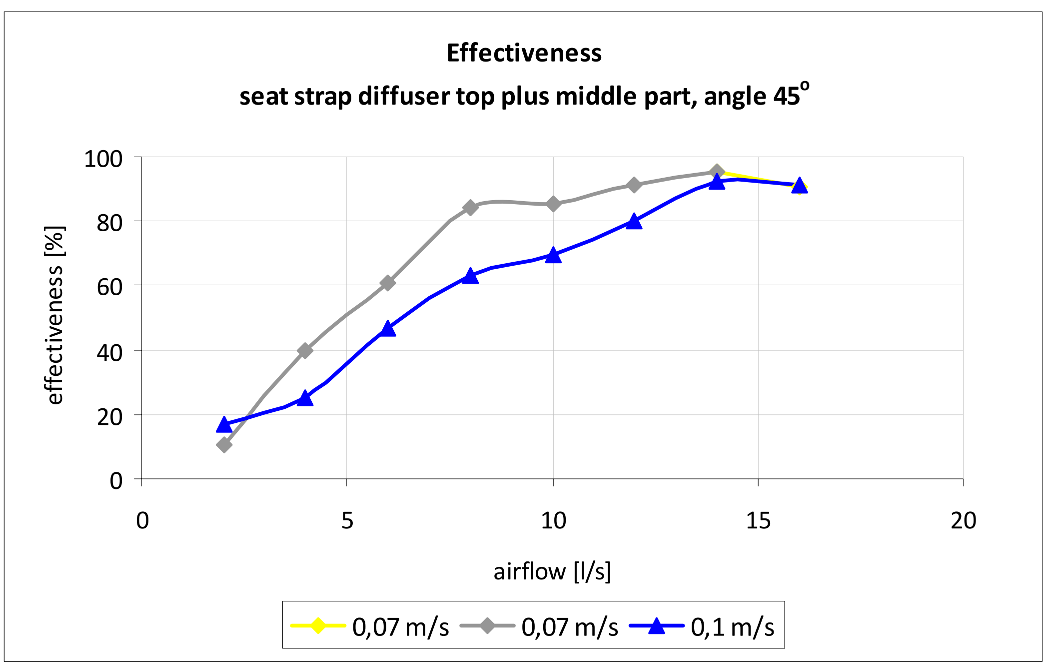



*Figure 7.1.12. Effectiveness graph for seat strap diffuser top plus middle part, angle 45° seat position 180°*

Effectiveness for velocity 0,1 m/s in the wind tunnel is surely correct but it is satisfied only for airflow over 14 l/s from PV diffuser. In other cases air supplied from middle part of seat strap diffuser seems to be blown away by high velocity before it reaches breathing zone.

Effectiveness results prove that top part in comparison with both parts of seat strap diffuser is more efficient. It can be an axiom, due to shape of diffuser, or can be caused by different amount of air coming from top part of each diffuser. The detailed explanation is as follows. Four identical pipes are used to supply air to top part of the diffuser. During experiments with both parts, two pipes supply top part and other two pipes supply middle part of the diffuser. In this way, whole airflow rate, which is provided by fan, is divided per 2 parts of the diffuser. This can mean that effectiveness for top part should not be compared with effectiveness for both parts of any diffusers for the same airflow.

### 7.1.6. Seat cover diffuser top part, angle 45°, seat position 180°

*Figure 7.1.13. Seat cover diffuser top plus middle part, angle 45°*

Measurements results of personalized ventilation effectiveness for aircraft seat placed in 180° position, with breathing function are presented below:

| *Seat cover diffuser top part, angle 45°* | | |
|---|---|---|
| *Airflow [l/s]* | *Effectiveness [%]* | |
| | *0,04 m/s* | *0,12 m/s* |
| 2 | 10,90 | 25,98 |
| 4 | 48,87 | 43,53 |
| 6 | 35,28 | 62,85 |
| 8 | 37,57 | 61,37 |
| 10 | 49,31 | 61,12 |
| 12 | 53,03 | 40,35 |

| | | |
|---|---|---|
| 14 | 60,61 | 36,53 |
| 15 | 59,30 | 41,58 |

*Table 7.1.7. Tracer gas measurements results for seat cover diffuser top part, angle 45°*

Top part of seat cover diffuser is tested for two velocities, each for seat position 180°. However, results for velocity 0,04 m/s in the wind tunnel are connected with problem described in Chapter 7.1.1., and they are marked on grey. In addition, these results are low so that there is no point to consider any combination of airflow from seat cover diffuser with such small velocity in the model.

According to velocity 0,12 m/s in the wind tunnel and airflow range which is correct in this setup, the maximal effectiveness is only 63%. Then for results for airflow higher than 10 l/s there is a problem of spreading tracer gas within the wind tunnel (see description in Chapter 7.1.1.) To prove that, concentration results are shown in Appendix C.

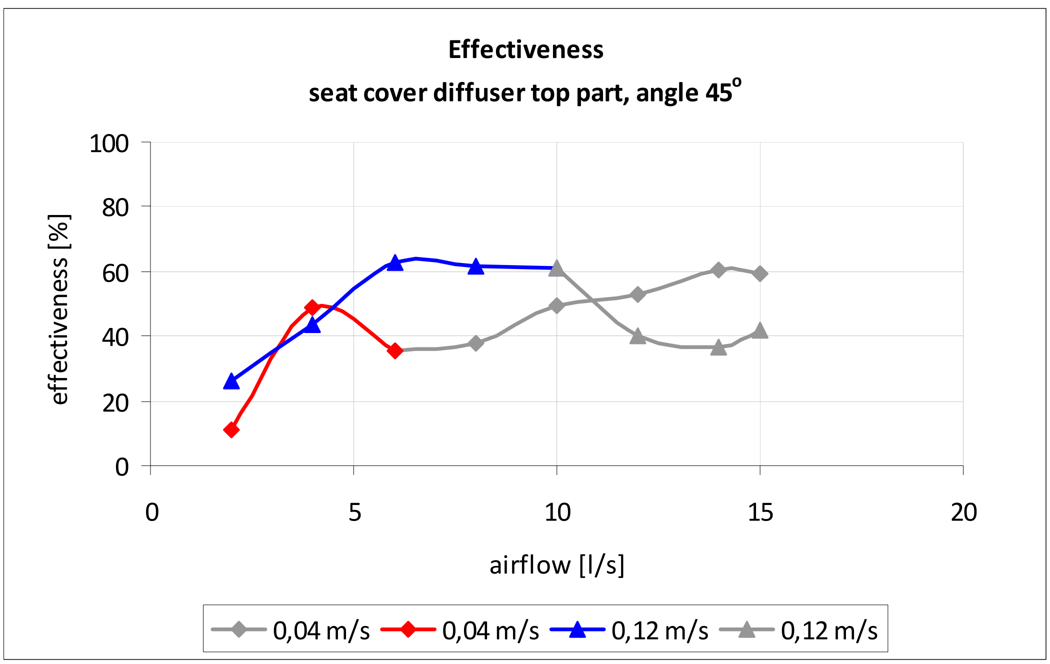



*Figure 7.1.14. Effectiveness graph for seat cover diffuser top part, angle 45° seat position 180°*

According to this fact, it is predicted that real effectiveness for top part of seat cover diffuser is much higher. Thus, it is necessary to make further investigation to confirm or refute that seat strap provides better effectiveness rather than seat cover. However, from thermal comfort point of view, seat strap diffuser causes less draft than seat cover in comparison with the same airflow.

### 7.1.7. Seat cover diffuser both parts, angle 45°, seat position 180°

*Figure 7.1.15. Seat cover diffuser top plus middle part, angle 45°*

Measurements results of personalized ventilation effectiveness for aircraft seat placed in 180° position, with breathing function are presented below:

| *Seat cover diffuser top plus middle part, angle 45°* | | |
|---|---|---|
| *Airflow [l/s]* | *Effectiveness [%]* | |
| | *0,04 m/s* | *0,1 m/s* |
| 2 | 14,15 | 10,87 |
| 4 | 17,26 | 23,88 |
| 6 | 35,48 | 20,67 |
| 8 | 66,64 | 20,67 |
| 10 | 59,47 | 39,96 |
| 12 | 74,82 | 35,85 |
| 14 | 69,51 | 34,16 |
| 16 | 74,73 | 24,37 |

*Table 7.1.8. Tracer gas measurements results for seat cover diffuser top plus middle part, angle 45°*

Both parts of seat cover diffuser are tested for velocity 0,04 m/s and 0,1 m/s in the wind tunnel.
Despite high effectiveness in case of velocity 0,04 m/s, these values are not representative due to unbalanced dependence between velocity in the wind tunnel and airflow from PV diffuser. Thus, they are marked on grey. The problem is more describe in Chapter 7.1.1.

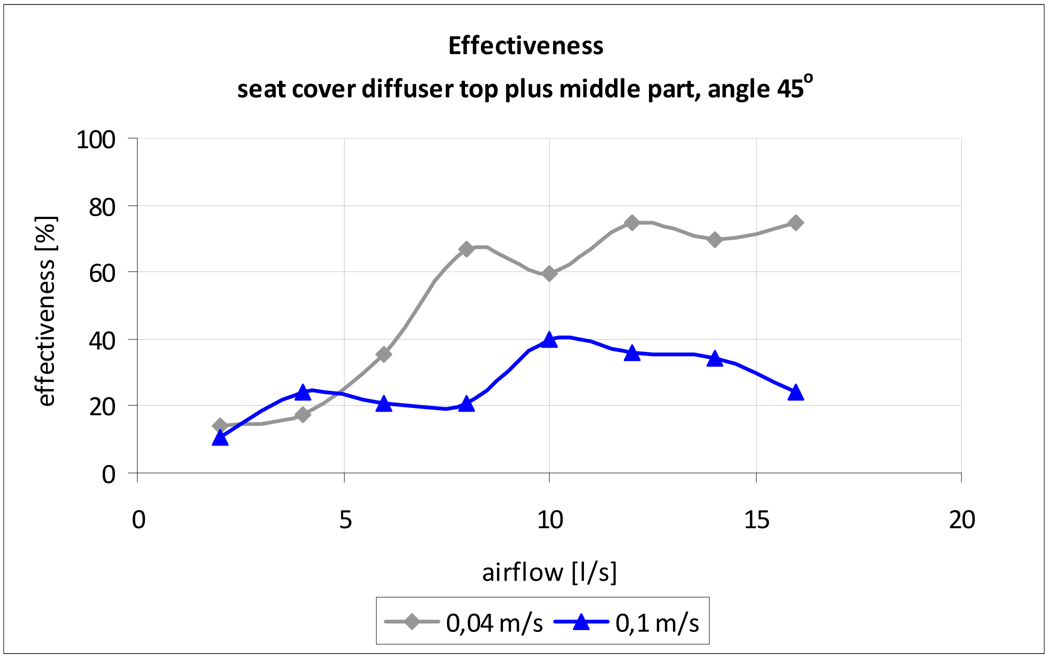



*Figure 7.1.16. Effectiveness graph for seat cover diffuser top plus middle part, angle 45° seat position 180°*

Effectiveness for velocity 0,1 m/s in the wind tunnel is surely correct but unfortunately values are not satisfied enough for any airflow from both parts of seat cover. The best effectiveness is reached for 10 l/s supplied to the PV diffusers and it is equal 40%.

## *7.2. Results for measurements in cabin section*

### 7.2.1. Problems occur during measurements in the cabin section

Because measurements take long time, verifying test is made, to check if time has influence on temperature and velocity results. The experiment takes 22 hours, and along this time, the following parameters are measured: temperature of supply and return air into/from the cabin section, temperature inside laboratory and maximal velocity inside the cabin section. Figures below show results from 22-hour test:

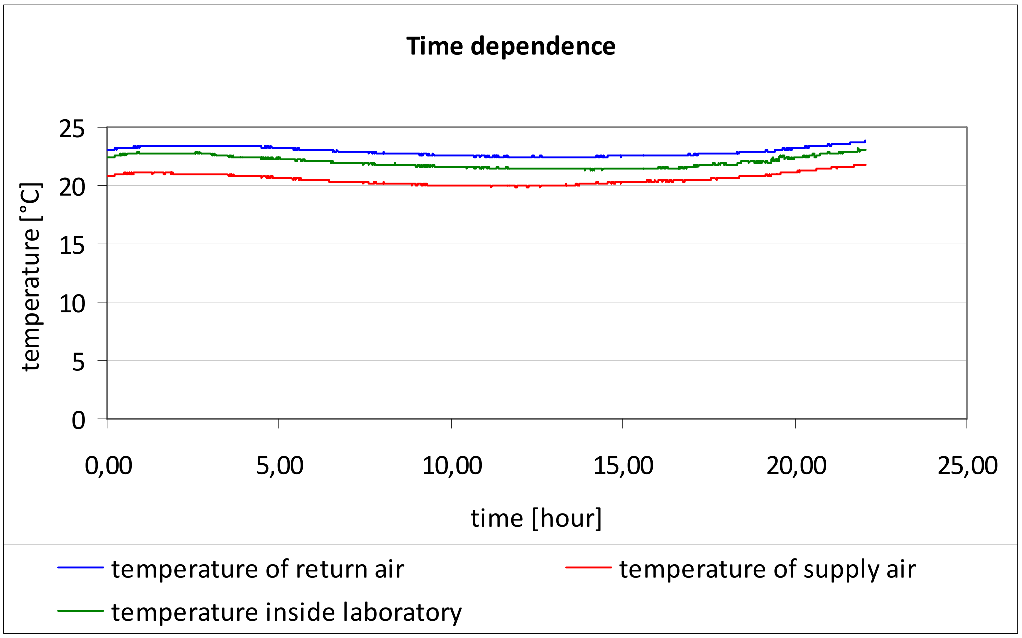



*Figure 7.2.1. Temperature dependence versus time*

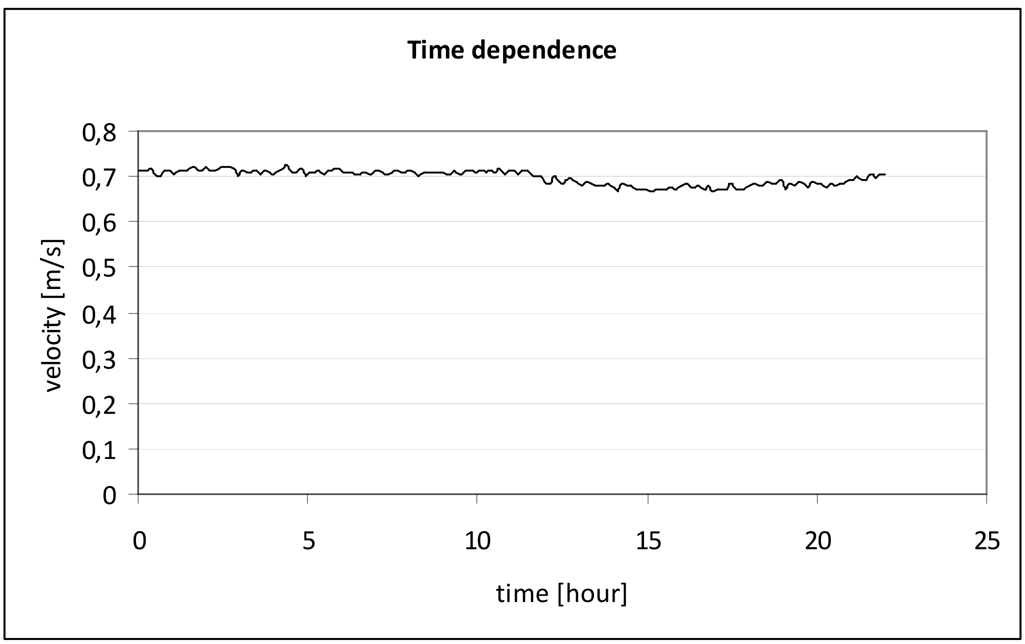



*Figure 7.2.2. Velocity as a function of time*

As it is show in Figure 7.2.1., all temperatures are changing considerably up to 2°C. During measurements supply temperature is checked constantly and in case of long variation, supply temperature (from outside the building) is mixed with air from laboratory to obtain demanding value. However, any automatic equipment is used.

It is apparent in Figure 7.2.2. that maximal velocity in the cabin section is changing up to 0,06 m/s. It can be caused by pressure changing outside the building.

Summarizing, unsteady conditions can be caused by following disturbances:

- temperature changes in the laboratory (
- temperature changes outside the laboratory (building) from where fresh air is supplied
- pressure changes in the supply and exhaust pipes due to time and wind
- velocity changes inside the cabin section
- leakages due to different conditions inside and outside the cabin section
- technical limitation with equipment during adjusting airflow value inside the cabin section, connected with manual control

### 7.2.2. Results for mixing ventilation (MV) in the cabin section

During this experiment fresh air is supplied from upper nozzle and contaminated air is exhausted by lower exhaust nozzle. One manikin exhales tracer gas and impact on the other manikin is measured.
Top part of seat cover diffuser is used. Acronym for this combine system is MV.

#### Temperature results

The assumption is made according to Chapter 6.3.3. In addition, steady conditions inside the model are assumed. Thus, temperature of supply airflow for 20 l/s or 10 l/s, should equal respectively:

$$T_s = 23 - \frac{160}{1005 \cdot 1{,}29 \cdot 0{,}02} \cong 16{,}83 \quad [\mathrm{K}] \qquad [7.2.1]$$

$$T_s = 23 - \frac{160}{1005 \cdot 1{,}29 \cdot 0{,}01} \cong 10{,}65 \quad [\mathrm{K}] \qquad [7.2.2]$$

However, sometimes it is impossible to obtain steady condition inside the cabin section, what causes differences between theoretical values calculated from formula [7.2.1] and [7.2.2] and real temperature of supply air into the model. Reasons for unstable conditions inside the cabin section are discussed in Chapter 7.2.1.

| Temperature results for MV | | | |
|---|---|---|---|
| Place | Supply airflow | | |
| | 20 l/s | 15 l/s | 10 l/s |
| [-] | [°C] | | |
| outside the model (in the laboratory) | 24,04 | 21,80 | 23,66 |
| supply pipe (outside the model) | 18,26 | 18,69 | 21,05 |
| return pipe (outside the model) | 23,17 | 22,06 | 23,29 |
| supply air (nozzle inside the model) | 19,78 | 19,70 | 21,98 |
| return air (nozzle inside the model) | 23,69 | 22,78 | 24,00 |
| on the anemometer | 23,54 | 23,34 | 25,19 |
| 10 cm above the floor in front of Comfortina | 23,40 | 22,54 | 24,17 |
| 10 cm above the floor in front of Monkey | 23,45 | 22,52 | 23,90 |
| 60 cm in front of Comfortina's head | 23,56 | 22,46 | 24,54 |
| 60 cm in front of Monkey's head | 23,36 | 22,33 | 24,40 |

*Table 7.2.1. Temperature results for mixing ventilation*

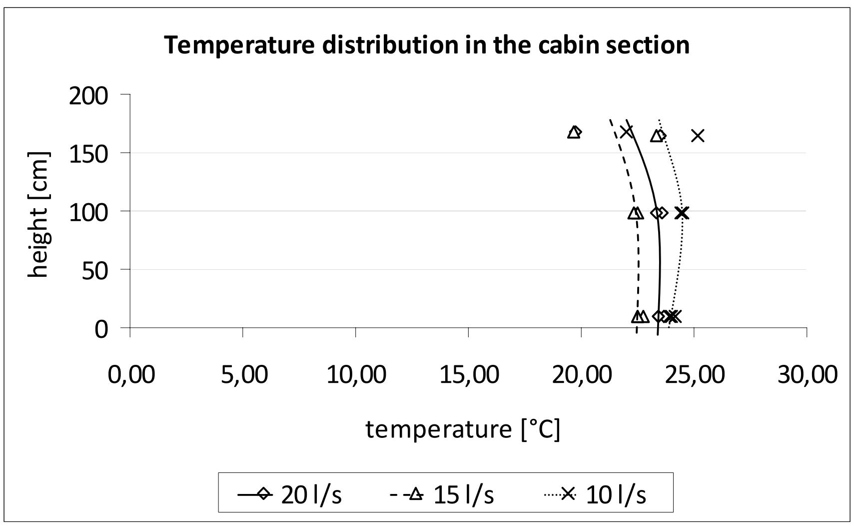



*Figure 7.2.3. Temperature distribution for mixing ventilation*

In Figure 7.2.3. it is apparent that temperature distribution inside the cabin section has typical shape for mixing ventilation. Thus, from temperature point of view, ventilation system works properly. Temperature is nearly the same in every point of cabin section. Differences are generally less than 0,5°C. Only one value, measured close to anemometer for 10l/s is higher than in rest monitor points. It can be caused by unsteady conditions inside the model. Nearly the same curve shape is obtained for different airflow. Small difference between shapes is mainly caused by different temperature of supply air through nozzles and a bit because of radiation from laboratory towards the model, for example:

| Temperature | | Supply air through nozzles [l/s] | | |
|---|---|---|---|---|
| | | 20 | 15 | 10 |
| In supply nozzle | [°C] | 19,78 | 19,70 | 21,98 |
| Inside laboratory | | 24,04 | 21,80 | 23,66 |

*Table 7.2.2. Differences within the range of temperature inside and outside the model*

There is only one small zone below the ceiling, adjacent to the diffuser where temperature is lower than in any other points of the cabin section. These values are represented by measurement point called ‘supply air (nozzle inside the model)’. Temperature in this zone is lower because supply air has high velocity (see velocity results). Furthermore, lower temperature should be supplied because of heat gains from manikins.

## Velocity results

| Velocity results for MV | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Supply airflow | Place | Height | Measurements no. | | | | | | | | Mean value |
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | |
| [l/s] | [-] | [cm] | [m/s] | [m/s] | [m/s] | [m/s] | [m/s] | [m/s] | [m/s] | [m/s] | [m/s] |
| 20 | maximal velocity | 164 | 0,573 | 0,581 | 0,561 | 0,575 | 0,576 | 0,585 | 0,585 | 0,597 | **0,579** |
| 15 | | | 0,442 | 0,440 | 0,456 | 0,470 | 0,441 | 0,451 | 0,462 | 0,472 | **0,454** |
| 10 | | | 0,271 | 0,275 | 0,274 | 0,280 | 0,276 | 0,280 | 0,281 | 0,276 | **0,277** |

*Table 7.2.3. Velocity results for mixing ventilation*

In Table 7.2.3. it is apparent that velocities for mixing ventilation are quite high. However, they are measured 4 cm below the ceiling where maximal velocity is what means, that cold air supply from diffuser will not directly affect passengers. It can be possible to feel draft in the corridor but it still depends on airflow rate from the diffuser. This kind of velocity profile is typical for flows close to ceiling (bounders).

## Concentration results

Table below illustrates air quality results in the breathing zone of sitting passengers (ventilation index $\varepsilon_p$) and air quality results for stewardess or people standing in a corridor (air quality index $\varepsilon_{oz}$).

| *Concentration results for MV* | | |
|---|---|---|
| *Supply airflow* | *Ventilation index* $\varepsilon_p$ | *Air quality index* $\varepsilon_{oz}$ |
| [l/s] | [-] | [-] |
| 20 | 0,94 | 0,79 |
| 15 | 0,96 | 0,82 |
| 10 | 0,99 | 0,71 |

*Table 7.2.4. Concentration results for mixing ventilation*

Figure 7.2.4. represents air quality in two cases which simultaneously occur during the flight. Ventilation index regards to sitting passengers. This value indicates the concentration of contaminants exhausting from the cabin in comparison to concentration of contaminants inhaled by sitting passenger. Unfortunately, none of tested cases are sufficient enough, because acceptable values of ventilation index starts above 1.

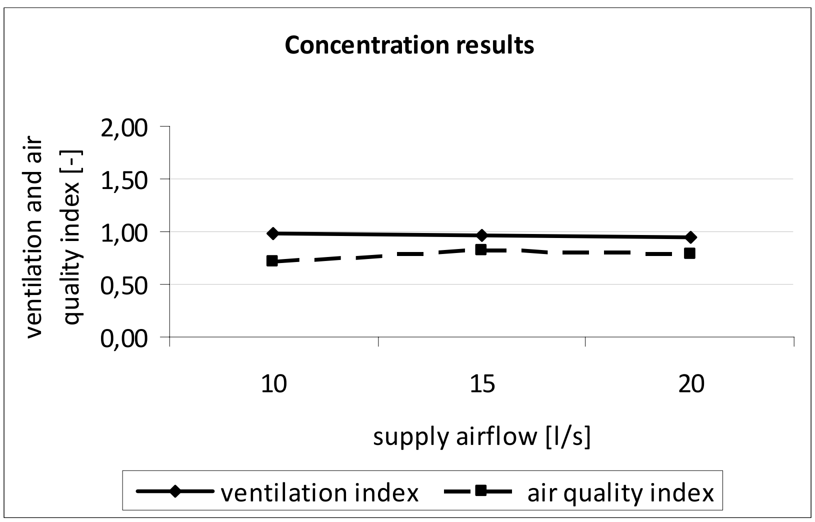



*Figure 7.2.4. Concentration results for mixing ventilation*

Air quality index is important for stewardesses or passengers standing in corridor. It indicates the level of clean air along the corridor on the person's head height. The same ratio should be reached as for ventilation index. Thus, as it is visible in the Figure 7.2.4., mixing ventilation in range of 10 – 20 l/s does not protect passengers and crew sufficiently from airborne contaminants in any place of the aircraft cabin.

### 7.2.3. Results for displacement ventilation (DV) in the cabin section

During this experiment fresh air is supplied from lower nozzle and contaminant air is exhausted by upper exhaust nozzle. One manikin exhales tracer gas and impact on the other manikin is measured.
Top part of seat cover diffuser is used. Acronym for this combine system is DV.

## Temperature results

The assumption is made according to Chapter 6.3.3. In addition, steady conditions inside the model are assumed. Thus, temperature of supply airflow should be counted like for mixing ventilation bases on formula [6.6] from Chapter 6.3.3.

| *Temperature results for DV* | | | |
|---|---|---|---|
| *Place* | *Supply airflow* | | |
| | *20 l/s* | *15 l/s* | *10 l/s* |
| [-] | [°C] | | |
| outside the model (in the laboratory) | 22,35 | 21,86 | 21,85 |
| supply pipe (outside the model) | 18,05 | 18,03 | 19,46 |
| return pipe (outside the model) | 22,64 | 22,22 | 22,16 |
| supply air (nozzle inside the model) | 18,50 | 18,78 | 19,89 |
| return air (nozzle inside the model) | 23,01 | 23,11 | 23,20 |
| on the anemometer | 23,04 | 23,10 | 23,48 |
| 10 cm above the floor in front of Comfortina | 21,04 | 21,18 | 21,31 |
| 10 cm above the floor in front of Monkey | 21,32 | 21,40 | 21,51 |
| 60 cm in front of Comfortina's head | 22,24 | 22,44 | 22,79 |
| 60 cm in front of Monkey's head | 22,28 | 22,42 | 22,70 |

*Table 7.2.5. Temperature results for displacement ventilation*

It is shown in Figure 7.2.5. that temperature inside the cabin section rises up with the height what is typical for displacement ventilation. Difference between cold supply air and hotter exhaust air depends on airflow from the diffuser. Values from Table 7.2.6. show that temperature difference within the cabin section can depend also on airflow rate and the value is smaller for smaller airflow.

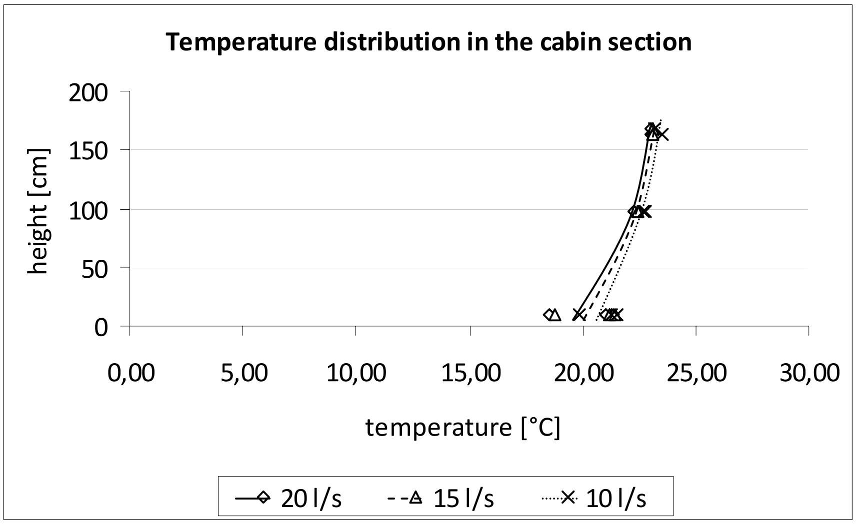



*Figure 7.2.5. Temperature distribution for displacement ventilation*

| *Item* | | *Supply air through nozzles [l/s]* | | |
|---|---|---|---|---|
| | | *20* | *15* | *10* |
| Difference between extreme temperatures inside the cabin section | [°C] | 4,51 | 4,33 | 3,31 |

*Table 7.2.6. Temperature differences inside the cabin section*

During measurements for displacement ventilation, temperature in upper zone of cabin section is nearly the same despite different temperature of supplying air. Thus, it can be good idea to measure the temperature in front of supply nozzle instead of inside, to obtain results that are more real. However, temperature inside laboratory is changing during measurements and it can have influence on the temperature inside the cabin section.

## Velocity results

| *Velocity results for DV* | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Supply airflow* | *Place* | *Measurements no.* | | | | | | | | *Mean value* |
| | | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | |
| [l/s] | [-] | [m/s] | [m/s] | [m/s] | [m/s] | [m/s] | [m/s] | [m/s] | [m/s] | [m/s] |
| 20 | maximal velocity - lower nozzle | 0,974 | 0,973 | 0,973 | 0,970 | 0,972 | 0,972 | 0,972 | 0,971 | **0,972** |
| 15 | | 0,927 | 0,936 | 0,929 | 0,928 | 0,929 | 0,930 | 0,928 | 0,930 | **0,930** |
| 10 | | 0,918 | 0,921 | 0,924 | 0,914 | 0,916 | 0,916 | 0,914 | 0,912 | **0,917** |

*Table 7.2.7. Velocity results for displacement ventilation*

Table 7.2.7. presents that velocities for displacement ventilation are quite high. They are measured just in the supply air nozzle, 5 cm above the floor where maximal velocity is. It is undoubtedly truth that cold air from the diffuser will affect passengers' thermal comfort, especially these who seat on the window seat. To lower velocity, it is suggested to change the shape and dimension of supply diffuser.

## Concentration results

Table below illustrates air quality results in the breathing zone of sitting passengers (ventilation index $\varepsilon_p$) and air quality results for stewardess (air quality index $\varepsilon_{oz}$).

| *Concentration results for DV* | | |
|---|---|---|
| *Supply airflow* | *Ventilation index* $\varepsilon_p$ | *Air quality index* $\varepsilon_{oz}$ |
| [l/s] | [-] | [-] |
| 20 | 0,86 | 1,64 |
| 15 | 1,13 | 1,00 |
| 10 | 1,13 | 0,55 |

*Table 7.2.8. Concentration results for displacement ventilation*

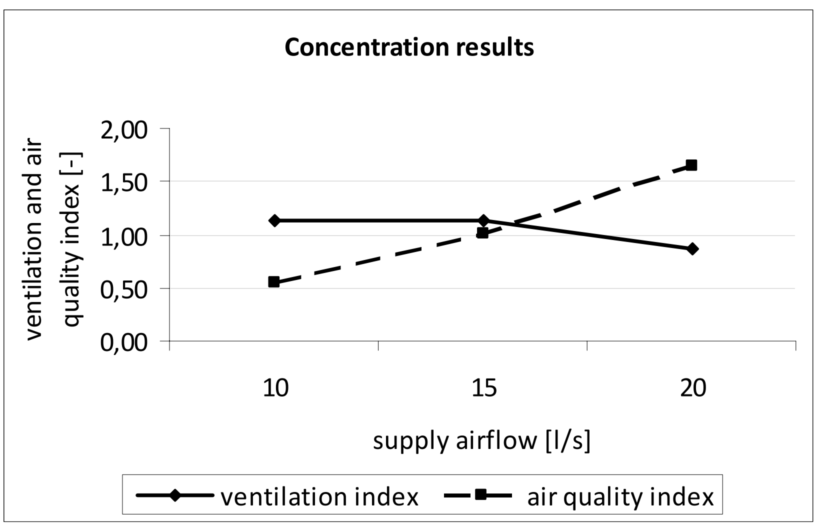



*Figure 7.2.6. Concentration results for displacement ventilation*

Concentration results are different than in case of mixing ventilation. For airflow less than 15 l/s the ventilation index is higher than in case of mixing ventilation. Then, for

higher airflows, both cases are not satisfactory because less contaminants are exhausted outside the cabin section than are inhaled by the manikin.
According to air quality in the corridor, air quality index increases simultaneously with airflow. It is advised if next investigations about displacement ventilation in aircraft are made, middle values should taken into consideration to cover protection both passengers and stewardesses.

### 7.2.4. Results for mixing ventilation combined with personal ventilation top part diffuser (MV+PV) in the cabin section

During this experiment clean air is supplied from upper nozzle and contaminant air is exhausted by lower exhaust nozzle. Additionally fresh air is directly supplied to the breathing zone by personal ventilation seat diffuser. One manikin exhales tracer gas and impact on the other manikin is measured.
Top part of seat cover diffuser is used. Acronym for this combine system is MV + PV.

## Temperature results

The assumption is made according to Chapter 6.3.3. In addition, steady conditions inside the model are assumed. Thus, temperature of supply airflow should be counted like for mixing ventilation bases on formula [6.6] from Chapter 6.3.3.

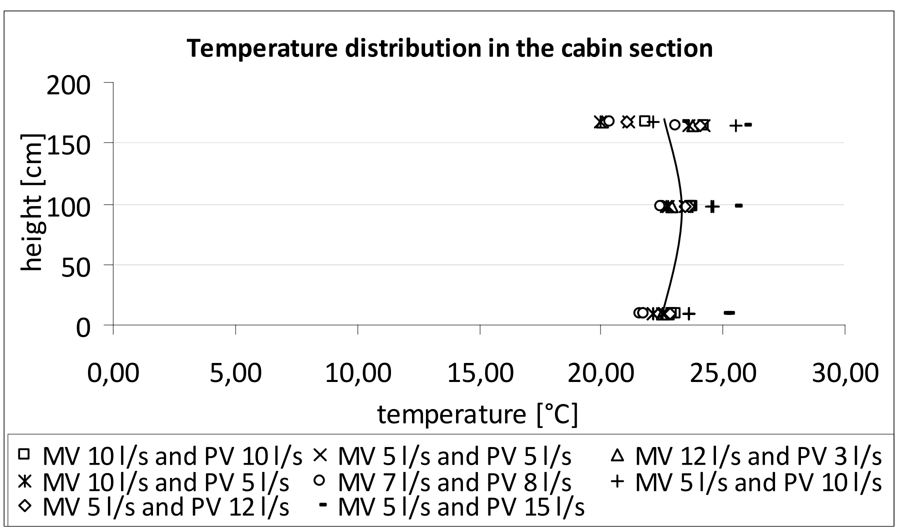



*Figure 7.2.7. Temperature distribution for combined ventilation (MV+PV) top part diffuser*

| Temperature results | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Place | Supply airflow | | | | | | | |
| | MV 10 / PV 10 | MV 5 / PV 5 | MV 12 / PV 3 | MV 10 / PV 5 | MV 7 / PV 8 | MV 5 / PV 10 | MV 3 / PV 12 | MV 5 / PV 15 |
| [-] | l/s / °C | l/s / °C | l/s / °C | l/s / °C | l/s / °C | l/s / °C | l/s / °C | l/s / °C |
| outside the model (in the laboratory) | 22,61 | 21,60 | 21,71 | 21,30 | 21,29 | 22,62 | 21,68 | 24,76 |
| supply pipe (outside the model) | 21,34 | 19,09 | 19,25 | 18,97 | 18,72 | 20,73 | 20,07 | 22,32 |
| return pipe (outside the model) | 22,55 | 22,12 | 21,90 | 21,60 | 21,16 | 22,99 | 22,36 | 24,71 |
| supply air (nozzle inside the model) | 21,84 | 21,13 | 20,07 | 19,98 | 20,36 | 22,11 | 21,02 | 23,40 |
| return air (nozzle inside the model) | 22,94 | 22,62 | 22,54 | 22,12 | 21,60 | 23,57 | 22,85 | 25,13 |
| on the anemometer | 24,18 | 24,18 | 23,75 | 23,58 | 23,08 | 25,50 | 24,03 | 25,93 |
| 10 cm above the floor in front of Comfortina | 23,09 | 22,63 | 22,73 | 22,50 | 21,78 | 23,62 | 22,77 | 25,25 |
| 10 cm above the floor in front of Monkey | 22,93 | 22,61 | 22,49 | 22,14 | 21,75 | 23,59 | 22,85 | 25,09 |
| 60 cm in front of Comfortina's head | 23,72 | 23,54 | 22,93 | 22,75 | 22,49 | 24,64 | 23,58 | 25,56 |
| 60 cm in front of Monkey's head | 23,64 | 23,47 | 22,87 | 22,68 | 22,44 | 24,55 | 23,43 | 25,53 |
| inside Monkey's PV diffuser | 22,96 | 21,66 | 23,47 | 22,63 | 21,46 | 24,24 | 22,35 | 24,58 |
| inside Comfortina's PV diffuser | 22,66 | 21,25 | 22,49 | 21,98 | 20,98 | 23,52 | 21,98 | 24,42 |

*Table 7.2.9. Temperature results for combined ventilation (MV+PV) top part diffuser*

As it is shown in Figure 7.2.3. and Figure 7.2.7. vertical temperature profile inside the cabin section has similar shape as well for mixing ventilation alone, as combined with personal ventilation. However, combined ventilation provides higher temperature differences within the cabin section – even up to 2°C in some setups.

One curve is made for all presented cases because each of them are similar. Sometimes curves are moved in comparison with others but still keep up the same shape. This situation is clearly visible for airflow MV 5 l/s and PV 15 l/s. Due to technical limitations of equipment, it is impossible to lower temperature neither inside the laboratory nor in supply air pipe. Thus, temperature values for this case are moved to the right in comparison with others.

One fan is used to supply air from laboratory to both personal ventilation diffusers. Temperature inside diffusers (behind the fan) is higher than primary temperature because of heat gains from the fan, for example:

| *Place* | *MV* | *PV* | *MV* | *PV* |
|---|---|---|---|---|
| | *10 l/s* | *10 l/s* | *5 l/s* | *5 l/s* |
| inside Monkey's PV diffuser | 22,96 °C | | 21,66 °C | |
| inside Comfortina's PV diffuser | 22,66 °C | | 21,25 °C | |
| inside the laboratory | 22,61 °C | | 21,60 °C | |

*Table 7.2.10. Temperature dependence for PV diffuser*

There is still small zone below the ceiling, adjacent to the diffuser where temperature is lower than in any other points of the cabin section. These values are represented by measurement point called 'supply air (nozzle inside the model)'. Temperature in this zone is lower because supply air has the highest velocity there (see velocity results).

## Velocity results

Velocities measured during experiment are resultants of all types of airflow in the cabin section. Basing on velocity results from Table 7.2.11. it can be truth that velocity in the cabin section mostly depends on airflow from nozzle situated below the ceiling. What means, that it indirectly depends on velocity from this diffuser. On the other hand, airflow from personal ventilation might cause spreading of free convection flows, and in this way can partly disturb horizontal flow.
Velocity in the corridor is mostly acceptable for cases within total airflow 15 l/s. Values are much smaller than in case of only mixing ventilation, what is desirable in thermal comfort. Table 7.2.12. shows, that difference within velocities in the cabin section in case of MV and MV+PV system is at least double.

| Velocity results | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Supply airflow | | Place | Height | Measurements no. | | | | | | | | Mean value |
| MV | PV | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | |
| [l/s] | [l/s] | [-] | [cm] | [m/s] | [m/s] | [m/s] | [m/s] | [m/s] | [m/s] | [m/s] | [m/s] | [m/s] |
| 10 | 10 | maximal velocity | 164 | 0,201 | 0,196 | 0,218 | 0,210 | 0,213 | 0,212 | 0,216 | 0,217 | 0,210 |
| 5 | 5 | maximal velocity | 164 | 0,137 | 0,134 | 0,144 | 0,140 | 0,139 | 0,145 | 0,135 | 0,136 | 0,139 |
| 12 | 3 | maximal velocity | 164 | 0,295 | 0,300 | 0,299 | 0,302 | 0,300 | 0,304 | 0,305 | 0,300 | 0,301 |
| 10 | 5 | maximal velocity | 164 | 0,235 | 0,235 | 0,230 | 0,232 | 0,227 | 0,235 | 0,225 | 0,236 | 0,232 |
| 7 | 8 | maximal velocity | 164 | 0,181 | 0,187 | 0,187 | 0,187 | 0,184 | 0,182 | 0,181 | 0,183 | 0,184 |
| 5 | 10 | maximal velocity | 164 | 0,121 | 0,118 | 0,123 | 0,117 | 0,117 | 0,122 | 0,137 | 0,134 | 0,124 |
| 3 | 12 | maximal velocity | 164 | 0,159 | 0,148 | 0,158 | 0,161 | 0,154 | 0,166 | 0,164 | 0,159 | 0,159 |
| 5 | 15 | maximal velocity | 164 | 0,198 | 0,191 | 0,194 | 0,197 | 0,197 | 0,195 | 0,199 | 0,209 | 0,198 |

*Table 7.2.11. Velocity results for combined ventilation (MV+PV) top part diffuser*

| Total airflow [l/s] | Velocity [m/s] | | Velocity difference [m/s] |
|---|---|---|---|
| | MV | MV+PV | |
| 20 | 0,579 | 0,204 | 0,375 |
| 15 | 0,454 | 0,200 | 0,254 |
| 10 | 0,277 | 0,139 | 0,138 |

*Table 7.2.12. Velocity difference between mixing and mixing plus personal ventilation system*

## Concentration results

Table below illustrates air quality results in the breathing zone of sitting passengers (ventilation index for system $\varepsilon_{exp,system}$) and air quality results for stewardess (air quality index $\varepsilon_{oz}$).

| *Concentration results for MV + PV* | | | |
|---|---|---|---|
| *Supply airflow from MV* | *Supply airflow from PV* | *Ventilation index for system* $\varepsilon_{exp,system}$ | *Air quality index* $\varepsilon_{oz}$ |
| [l/s] | [l/s] | [-] | [-] |
| 10 | 10 | 0,9 | 0,83 |
| 5 | 5 | 1,06 | 1,28 |
| 12 | 3 | 0,98 | 0,79 |
| 10 | 5 | 0,98 | 0,83 |
| 7 | 8 | 1,05 | 0,85 |
| 5 | 10 | 1,21 | 0,93 |
| 3 | 12 | 1,53 | 0,76 |
| 5 | 15 | 0,86 | 0,48 |

*Table 7.2.13. Concentration results for combined ventilation (MV+PV) top part diffuser*

According to results from Table 7.2.13. illustrated in figure below, mixing ventilation in combination with personal ventilation system provides much cleaner air to the passenger breathing zone than single system. It is worth to remind that ventilation index for MV only does not reach minimal acceptable value for none of tested airflow while for combine system easily equals more than 1.

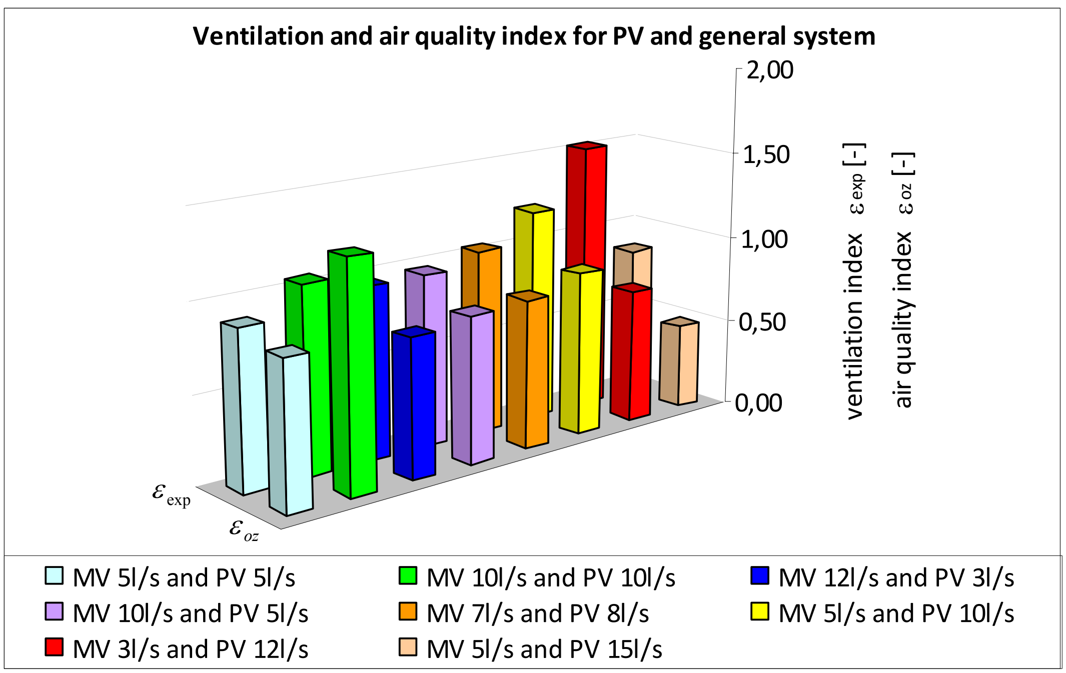



*Figure 7.2.8. Ventilation and air quality index for PV and general system (MV+PV)*

The highest value of ventilation index is for total airflow 15 l/s and it is higher for higher airflow from PV diffuser. Air quality in the stewardess breathing zone reaches acceptable level over 1 only for 5 l/s supplied from each diffuser and in other cases it varies from 0,5 to 0,9.

It is advised to combine 3 l/s from MV system with 12 l/s from PV diffuser. This correlation provides the highest ventilation index 1,53 and air quality index equals 0,76. However, the second one can be increased by some improvements, such as additional nozzles on the edge of overhead shelf.

Table below and Figure 7.2.9. concern on the case when whole exhaust from the cabin section is set to 15 l/s, what comes from different combination of flows from MV and PV systems.

| *Whole exhaust from cabin section* | *Supply airflow from MV (upper nozzle)* | *Supply airflow from PV* | *Ventilation index for system (MV+PV)* | *Ventilation index for MV only* |
|---|---|---|---|---|
| [l/s] | [l/s] | [l/s] | [-] | [-] |
| 15 | 12 | 3 | 0,98 | 0,96 |
| | 10 | 5 | 0,98 | |
| | 7 | 8 | 1,05 | |
| | 5 | 10 | 1,21 | |
| | 3 | 12 | 1,53 | |

*Table 7.2.14. Comparison ventilation index for different ventilation systems, for constant exhaust value 15 l/s*

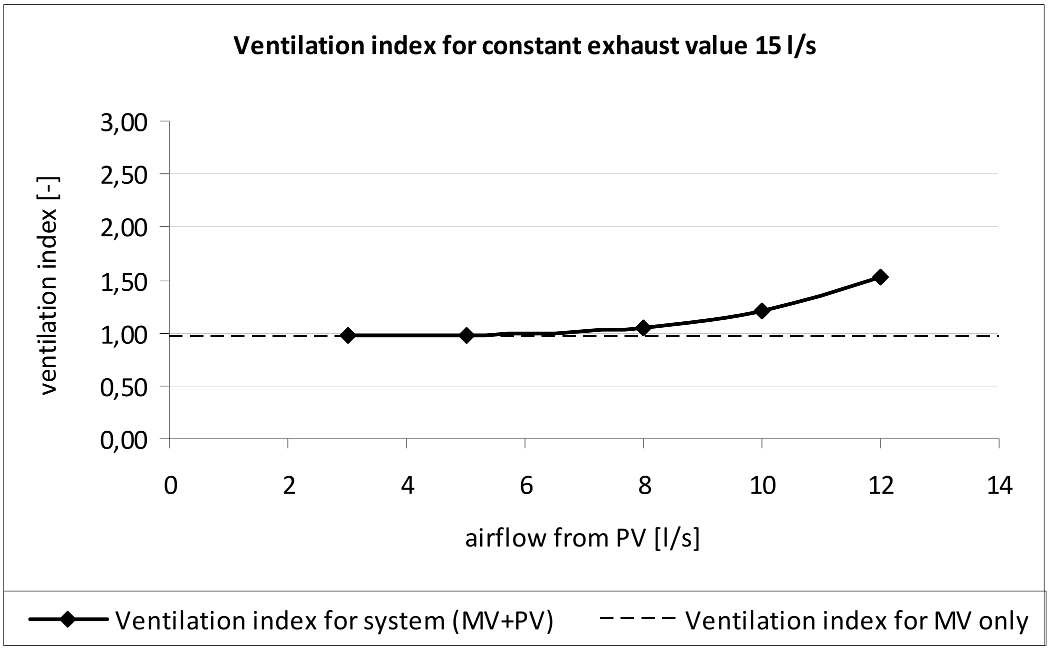



*Figure 7.2.9. Comparison ventilation index for different ventilation systems, for constant exhaust value 15 l/s*

Combine ventilation system is much more efficient rather than using alone one. In Figure 7.2.9 it is noticeable that increases of airflow from personal diffuser, what means decreases of airflow from upper nozzle (MV) to have total airflow 15 l/s in the cabin section, causes increasing efficiency of whole combine system in comparison with only mixing ventilation system.

Ventilation index in both cases has nearly the same values if smaller airflow from PV diffuser than 5 l/s per 2 persons is supplied.

### 7.2.5. Results for displacement ventilation combined with personal ventilation top part diffuser (DV+PV) in the cabin section

During this experiment clean air is supplied from lower nozzle and contaminant air is exhausted by upper exhaust nozzle. Additionally fresh air is directly supplied to the breathing zone by personal ventilation seat diffuser. One manikin exhales tracer gas and impact on the other manikin is measured.
Top part of seat cover diffuser is used. Acronym for this combine system is DV + PV.

### Temperature results

The assumption is made according to Chapter 6.3.3. In addition, steady conditions inside the model are assumed. Thus, temperature of supply airflow should be counted like for mixing ventilation bases on formula [6.6] from Chapter 6.3.3.

| Temperature results | | | | | | | |
|---|---|---|---|---|---|---|---|
| Place | Supply airflow | | | | | | |
| | MV 5 / PV 5 | MV 5 / PV 10 | MV 15 / PV 5 | MV 12 / PV 8 | MV 10 / PV 10 | MV 7 / PV 13 | MV 5 / PV 15 |
| [-] | l/s / °C | l/s / °C | l/s / °C | l/s / °C | l/s / °C | l/s / °C | l/s / °C |
| outside the model (in the laboratory) | 21,45 | 21,66 | 21,27 | 21,21 | 21,43 | 21,07 | 21,14 |
| supply pipe (outside the model) | 19,80 | 20,27 | 18,46 | 18,58 | 19,22 | 18,67 | 19,35 |
| return pipe (outside the model) | 22,34 | 22,68 | 22,30 | 21,92 | 22,32 | 22,18 | 22,29 |
| supply air (nozzle inside the model) | 19,70 | 20,15 | 18,59 | 18,62 | 19,28 | 18,90 | 19,37 |
| return air (nozzle inside the model) | 23,32 | 23,60 | 22,98 | 22,58 | 23,05 | 22,84 | 23,05 |
| on the anemometer | 23,40 | 23,41 | 22,71 | 22,02 | 22,57 | 22,40 | 22,84 |
| 10 cm above the floor in front of Comfortina | 21,25 | 21,55 | 20,71 | 20,35 | 20,94 | 20,64 | 20,98 |
| 10 cm above the floor in front of Monkey | 21,41 | 21,62 | 20,93 | 20,53 | 21,19 | 20,76 | 21,11 |
| 60 cm in front of Comfortina's head | 22,87 | 22,98 | 22,04 | 21,80 | 22,24 | 22,15 | 22,32 |
| 60 cm in front of Monkey's head | 22,78 | 22,93 | 22,02 | 21,72 | 22,17 | 22,13 | 22,28 |
| inside Monkey's PV diffuser | 22,34 | 21,92 | 21,89 | 20,68 | 21,12 | 20,83 | 21,28 |
| inside Comfortina's PV diffuser | 21,62 | 21,43 | 21,26 | 20,27 | 20,75 | 20,57 | 20,99 |

*Table 7.2.15. Temperature results for combined ventilation (DV+PV) top part diffuser*

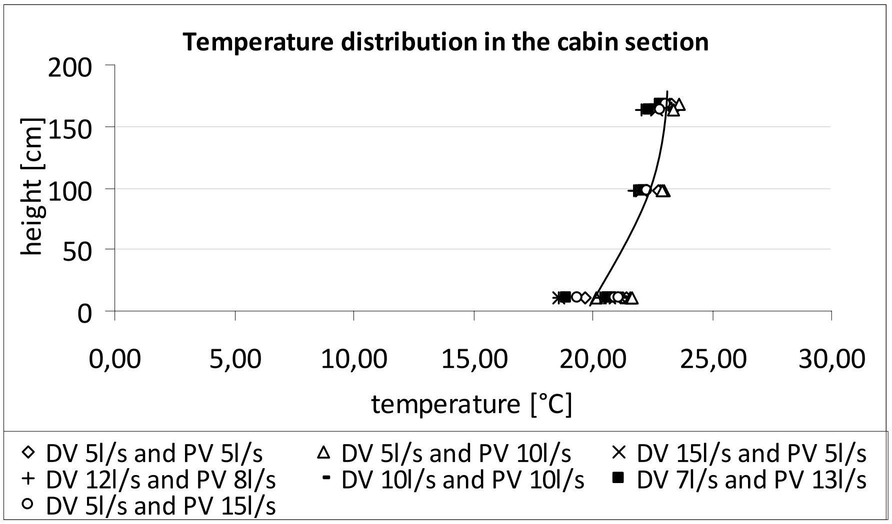



*Figure 7.2.10. Temperature distribution for combined ventilation (DV+PV) top part diffuser*

In Figure 7.2.10. it is apparent that temperature inside the cabin section rises up with the height, what is typical for displacement ventilation. Difference between cold supply air and hotter exhaust air depends on airflow from the diffuser, and they are similar to temperature differences for DV system. They varies from 3,45 °C to 4,39 °C.

One curve is made for all presented cases because each of them are similar. It is noteworthy that temperature in the laboratory is much stable during this measurements rather than in previous ones.

One fan is used to supply air from laboratory to both personal ventilation diffusers. Temperature inside diffusers (behind the fan) can be higher than primary temperature because of heat gains from the fan. However, as it is shown on example below, this situation is not a rule. Temperature inside diffuser is measure by only one thermocouple. Moreover, heat gains from the manikin can differently influence the results.

| *Place* | *MV* | *PV* | *MV* | *PV* |
|---|---|---|---|---|
| | *10 l/s* | *10 l/s* | *5 l/s* | *5 l/s* |
| inside Monkey's PV diffuser | 21,12 °C | | 22,34 °C | |
| inside Comfortina's PV diffuser | 20,75 °C | | 21,62 °C | |
| inside the laboratory | 21,43 °C | | 21,45 °C | |

*Table 7.2.16. Temperature dependence for PV diffuser*

## Velocity results

| Velocity results | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Supply airflow* | | *Place* | *Measurements no.* | | | | | | | | *Mean value* |
| *DV* | *PV* | | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | |
| [l/s] | [l/s] | [-] | [m/s] | [m/s] | [m/s] | [m/s] | [m/s] | [m/s] | [m/s] | [m/s] | [m/s] |
| 5 | 5 | maximal velocity - lower nozzle | 0,304 | 0,308 | 0,315 | 0,320 | 0,341 | 0,346 | 0,332 | 0,345 | **0,326** |
| 5 | 10 | maximal velocity - lower nozzle | 0,431 | 0,456 | 0,462 | 0,481 | 0,445 | 0,443 | 0,468 | 0,449 | **0,454** |
| 15 | 5 | maximal velocity - lower nozzle | 0,980 | 0,980 | 0,982 | 0,980 | 0,983 | 0,982 | 0,982 | 0,983 | **0,982** |
| 12 | 8 | maximal velocity - lower nozzle | 0,969 | 0,965 | 0,971 | 0,965 | 0,971 | 0,969 | 0,968 | 0,969 | **0,968** |
| 10 | 10 | maximal velocity - lower nozzle | 0,938 | 0,938 | 0,938 | 0,937 | 0,926 | 0,931 | 0,934 | 0,934 | **0,935** |
| 7 | 13 | maximal velocity - lower nozzle | 0,453 | 0,476 | 0,470 | 0,464 | 0,469 | 0,477 | 0,470 | 0,490 | **0,471** |
| 5 | 15 | maximal velocity - lower nozzle | 0,418 | 0,427 | 0,431 | 0,436 | 0,415 | 0,432 | 0,449 | 0,432 | **0,430** |

*Table 7.2.17. Velocity results for combined ventilation (DV+PV) top part diffuser*

Table 7.2.17. presents that velocities which appear, in case of this setup, are quite high. Anemometer is located in the supply air nozzle 5 cm above the floor where maximal velocity is. That means that velocity near passenger's legs will be similar to the value showed in Table 7.2.17. The worst case provides velocity nearly 1 m/s what is 5 times more than preferred for thermal comfort. It is undoubtedly truth that cold air from nozzle will affect passengers, especially these who seat on the window seat.

It is sure, that velocity in lower zone (near passenger's legs) depends mostly on supply airflow from lower diffuser and only in minority on supply air from PV diffuser. According to this, low airflow from DV diffuser should be taken into further consideration (such as 5 l/s from DV diffuser and 15 l/s from PV). Additionally, to lower velocity, it is suggested to make further investigations for different shape and dimension of supply slot.

## Concentration results

Table below illustrates air quality results in the breathing zone of sitting passengers (ventilation index for system $\varepsilon_{exp,system}$) and air quality results for stewardess (air quality index $\varepsilon_{oz}$).

| Concentration results for DV + PV | | | |
|---|---|---|---|
| *Supply airflow from DV* | *Supply airflow from PV* | *Ventilation index for system* $\varepsilon_{exp,system}$ | *Air quality index* $\varepsilon_{oz}$ |
| [l/s] | [l/s] | [-] | [-] |
| 5 | 5 | 1,00 | 0,55 |
| 5 | 10 | 1,14 | 0,47 |
| 15 | 5 | 0,82 | 0,62 |
| 12 | 8 | 1,39 | 0,41 |
| 10 | 10 | 1,57 | 0,36 |
| 7 | 13 | 4,56 | 0,42 |
| 5 | 15 | 5,42 | 0,39 |

*Table 7.2.18. Concentration results for combined ventilation (DV+PV) top part diffuser*

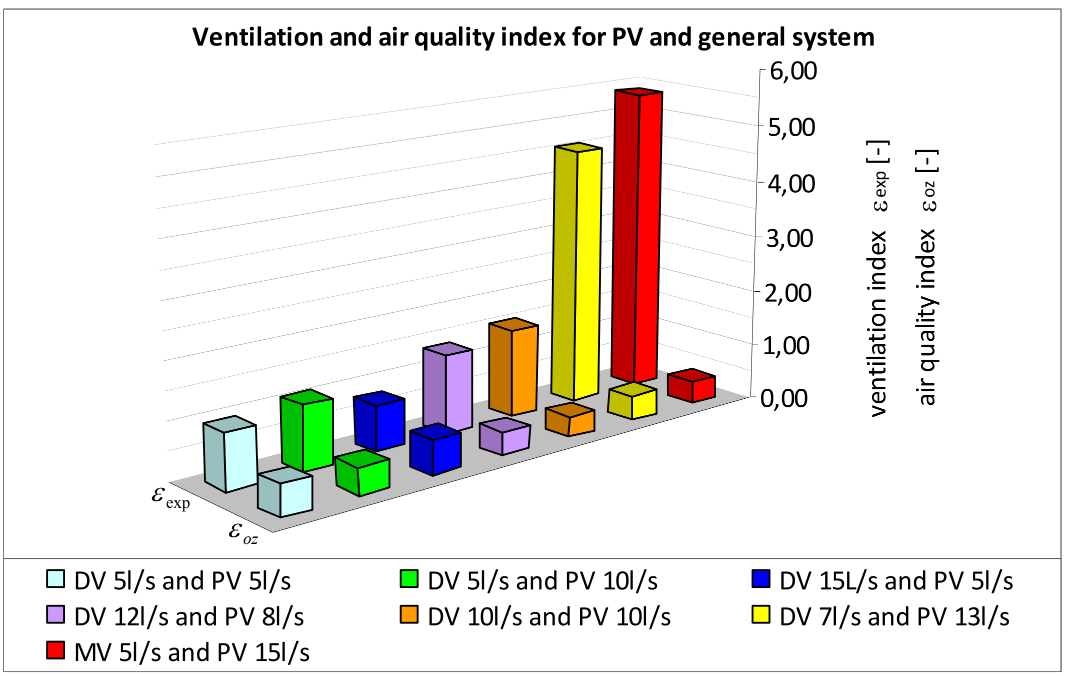



*Figure 7.2.11. Ventilation index for PV and general system (DV+PV)*

According to results from Table 7.2.18. illustrated in figure above, displacement ventilation in combination with personal ventilation system provides definitely more cleaner air to the passenger breathing zone than single system. It is worth to remind that ventilation index for DV system varies around minimal acceptable value (1) for each of tested airflow while for combine system ventilation index can reach even 5,42.

Air quality index is not high enough in any case of this setup (DV + PV), and in average equals 0,5. This low value is caused by warm plum of contaminants moving upwardly from passenger's breathing zone to the stewardess's breathing zone. However, air quality can be increased by some improvements, such as additional nozzles on the edge of overhead shelf.

Table below and Figure 7.2.12. concern on the case when whole exhaust from the cabin section is set to 20 l/s, what comes from different combination of flows from DV and PV systems.

| *Whole exhaust from cabin section* | *Supply airflow from DV (lower nozzle)* | *Supply airflow from PV* | *Ventilation index for system (DV+PV)* | *Ventilation index for DV only* |
|---|---|---|---|---|
| [l/s] | [l/s] | [l/s] | [-] | [-] |
| 20 | 15 | 5 | 0,82 | 0,86 |
| | 12 | 8 | 1,39 | |
| | 10 | 10 | 1,57 | |
| | 7 | 13 | 4,56 | |
| | 5 | 15 | 5,42 | |

*Table 7.2.19. Comparison ventilation index for different ventilation systems, for constant exhaust value 20 l/s*

Displacement ventilation in combination with personal ventilation system provides ventilation index nearly always higher than in case of displacement ventilation system alone.

As it is shown in Figure 7.2.12 increases of airflow from personal diffuser, what means decreases of airflow from lower nozzle (DV) to have total airflow 20 l/s, causes higher efficiency of whole combine system in comparison with only displacement ventilation system.

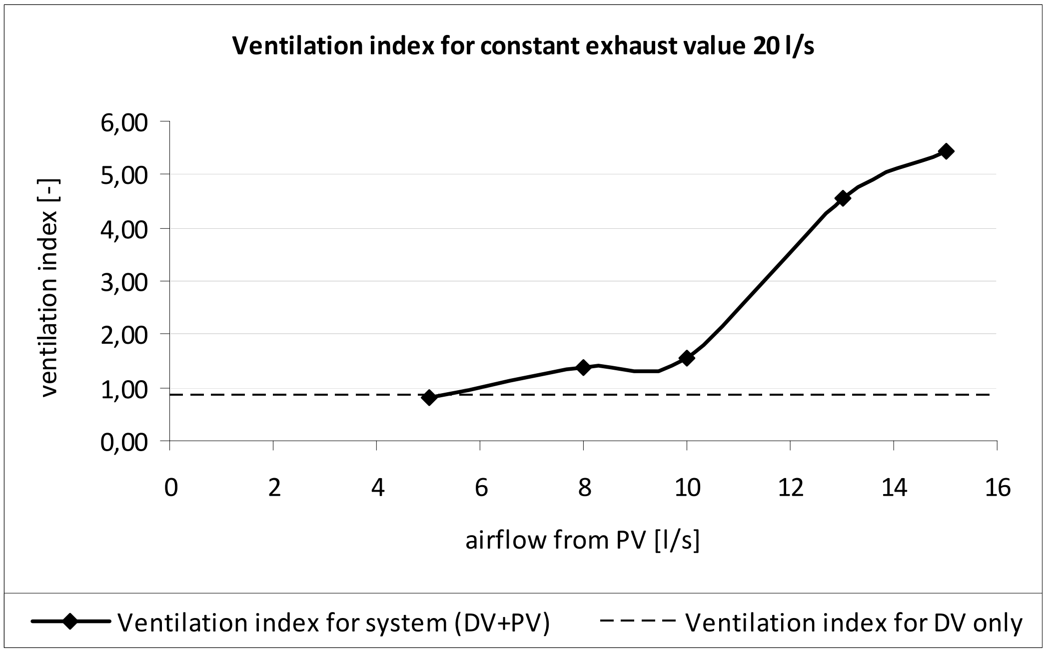



*Figure 7.2.12. Comparison ventilation index for different ventilation systems, for constant exhaust value 20 l/s*

The highest ventilation index (5,42) is noted for 5 l/s from DV diffuser and 15 l/s from PV diffuser. It is worth to add, that high airflow from PV diffuser can cause local discomfort because passenger can feel draft on the neck. However, in this experiment each airflow from PV diffuser is divided by 2 persons thus physically only 7,5 l/s is supplied by seat cover, what refers to velocity 0,06 m/s from one PV diffuser.

### 7.2.6. Summary of results for top part diffuser for measurements in the cabin section

Based on all results it is suggested to use combine ventilation system for further consideration. Figure below presents ventilation index values for different ventilation system and different total airflow.

| *Total airflow* | *airflow supply from MV diffuser* | *airflow supply from DV diffuser* | *airflow supply from PV diffuser* | *Ventilation index $\varepsilon_{exp}$* |
|---|---|---|---|---|
| [l/s] | | | | [-] |
| 10 | 5 | | 5 | 1,06 |
| | | 5 | 5 | 1,00 |
| 15 | 12 | | 3 | 0,98 |
| | 10 | | 5 | 0,98 |

| | | | | |
|---|---|---|---|---|
| | 7 | | 8 | 1,05 |
| | 5 | | 10 | 1,21 |
| | | 5 | 10 | 1,14 |
| | 3 | | 12 | 1,53 |
| 20 | | 15 | 5 | 0,82 |
| | | 12 | 8 | 1,39 |
| | 10 | | 10 | 0,9 |
| | | 10 | 10 | 1,57 |
| | | 7 | 13 | 4,56 |
| | 5 | | 15 | 0,86 |
| | | 5 | 15 | 5,42 |

*Table 7.2.20. Ventilation index for combine ventilation systems and for different airflow*

Table 7.2.20. is illustrated on pictorial Figure 7.2.13. It is visible that for total airflow 15 l/s the best ventilation index (1,53) is obtained for mixing ventilation combined with personal ventilation system. In detail, it is 3 l/s from MV and 12 l/s from PV diffuser. Maximal velocity is quite small in this combination and it is equal 0,159 m/s (measuring point is situated 4 cm below the ceiling).
Other good correlation is obtained for mixing and personal ventilation for 5 l/s from MV and 10 l/s from PV diffuser. Ventilation index, in this case, is equal 1,21 and maximal velocity 0,124 m/s

For total airflow 20 l/s the best cases are reached for displacement ventilation combined with personal ventilation system. One combination is 5 l/s supply from DV plus 15 l/s supply from PV diffuser and second one is for 7 l/s from DV plus 13 l/s from PV diffuser. However, the use of displacement ventilation in aircraft is connected with high velocity of cold air near passenger's legs, which for presented cases equals respectively 0,47 m/s and 0,43 m/s. Moreover, high airflow from personal ventilation diffuser is often connected with draft feeling, thus, if final setup includes high airflow from PV, local thermal comfort for different temperatures of supply air has to be investigated. Base on equivalent homogeneous temperature (EHT) described in 'New Solution For Personalized Ventilation in Aircrafts', the thermal comfort around passenger's head should be especially taken into consideration. [1]

There is no point to consider air quality index during choosing the best combination of airflow and general system. It is due to the fact, that its value is satisfying only for mixing ventilation combined with personal ventilation for 5 l/s from both diffusers. For other cases it does not reach acceptable level (equal 1). However, air quality can be increased by some improvements, such as additional nozzles on the edge of overhead shelf.

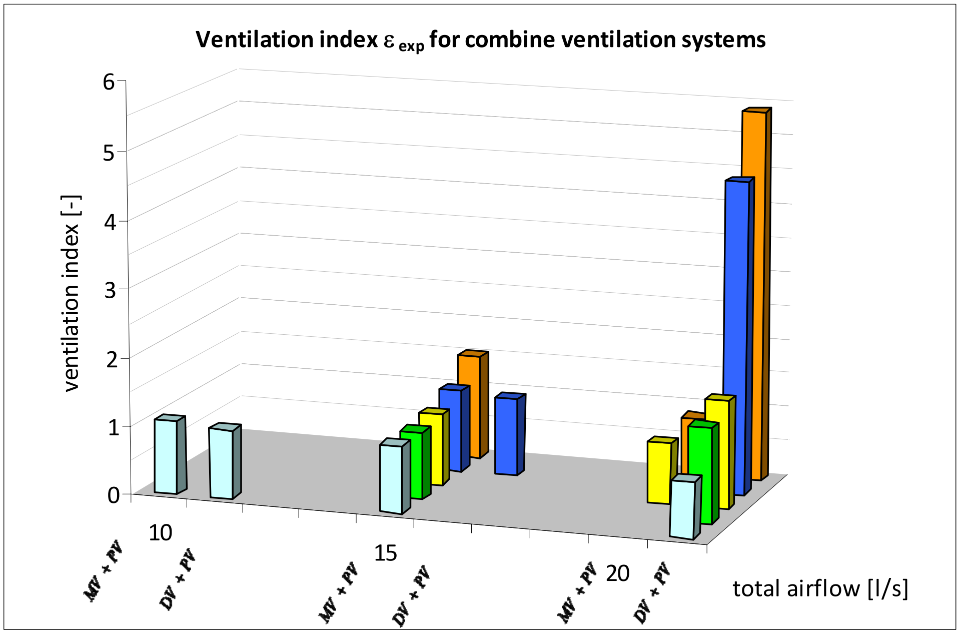



*Figure 7.2.13. Pictorial graph; ventilation index for different ventilation system and different total airflow*

## 7.2.7. Additional results for seat strap diffuser in the cabin section

| *Concentration results for seat strap top part, MV + PV* | | | |
|---|---|---|---|
| *Supply airflow from MV* | *Supply airflow from PV* | *Ventilation index for system* $\varepsilon_{exp,system}$ | *Air quality index* $\varepsilon_{oz}$ |
| [l/s] | [l/s] | [-] | [-] |
| 3 | 12 | **1,77** | **0,96** |

*Table 7.2.21. Concentration results for combined ventilation (MV+PV) top part of seat strap diffuser*

| *Concentration results for seat strap top part, DV + PV* | | | |
|---|---|---|---|
| *Supply airflow from DV* | *Supply airflow from PV* | *Ventilation index for system* $\varepsilon_{exp,system}$ | *Air quality index* $\varepsilon_{oz}$ |
| [l/s] | [l/s] | [-] | [-] |
| 5 | 15 | **2,48** | **0,71** |

*Table 7.2.22. Concentration results for combined ventilation (DV+PV) top part of seat strap diffuser*

| *Concentration results for seat strap middle part, MV + PV* | | | |
|---|---|---|---|
| *Supply airflow from MV* | *Supply airflow from PV* | *Ventilation index for system* $\varepsilon_{exp,system}$ | *Air quality index* $\varepsilon_{oz}$ |
| [l/s] | [l/s] | [-] | [-] |
| 3 | 12 | **1,07** | **0,67** |

*Table 7.2.23. Concentration results for combined ventilation (MV+PV) middle part of seat strap diffuser*

| *Concentration results for seat strap middle part, DV + PV* | | | |
|---|---|---|---|
| *Supply airflow from DV* | *Supply airflow from PV* | *Ventilation index for system* $\varepsilon_{exp,system}$ | *Air quality index* $\varepsilon_{oz}$ |
| [l/s] | [l/s] | [-] | [-] |
| 5 | 15 | **1,64** | **0,62** |

*Table 7.2.24. Concentration results for combined ventilation (DV+PV) middle part of seat strap diffuser*

| *Concentration results for seat strap both parts, MV + PV* | | | |
|---|---|---|---|
| *Supply airflow from MV* | *Supply airflow from PV* | *Ventilation index for system* $\varepsilon_{exp,system}$ | *Air quality index* $\varepsilon_{oz}$ |
| [l/s] | [l/s] | [-] | [-] |
| 3 | 12 | **1,44** | **0,54** |

*Table 7.2.25. Concentration results for combined ventilation (MV+PV) both parts of seat strap diffuser*

| *Concentration results for seat strap both parts, DV + PV* | | | |
|---|---|---|---|
| *Supply airflow from DV* | *Supply airflow from PV* | *Ventilation index for system* $\varepsilon_{exp,system}$ | *Air quality index* $\varepsilon_{oz}$ |
| [l/s] | [l/s] | [-] | [-] |
| 5 | 15 | **1,31** | **2,00** |

*Table 7.2.26. Concentration results for combined ventilation (DV+PV) both parts of seat strap diffuser*

Tables above clearly show results for different parts of seat strap diffuser. All measurements are done for extreme cases of each combine ventilation system.
Bases on ventilation index for the same value of airflow supplied to different parts of both diffusers, the following comparison can be made.

| *Results* | *3MV+12PV (seat cover and seat strap)* | *5DV+15PV (seat cover and seat strap)* |
|---|---|---|
| the best | top part | top part |
| - | both parts | middle part |
| the worst | middle part | both parts |

*Table 6.2.27. Efficiency of parts of the diffuser for both ventilation systems*

It is apparent in Table 7.2.27. that top part of PV diffuser is the most efficiency diffuser and it neither depend on type of ventilation system nor kind of diffuser (seat cover or seat strap)

Thus, to compare seat cover with seat strap diffuser only top part is taken into consideration with following results.

| *Results* | *3MV+12PV* | *5DV+15PV* |
|---|---|---|
| the best | seat strap | seat cover |
| the worst | seat cover | seat strap |

*Table 6.2.28. Efficiency of both types PV diffusers for both ventilation systems*

Table 7.2.28. compares seat strap and seat cover diffuser bases on extreme setup for each ventilation system. Seat strap provides higher ventilation index than seat cover in case of using MV+PV system, but in case of DV+PV system it is inversely.

Summarize if MV+PV system is used, the most efficiency is obtained with seat strap top part. Than in case of DV+PV system, seat cover top part is number one.

## *7.3. Smoke simulation results*

Smoke simulations are made in order to visualize how the angled seat cover works in all combined systems. Thanks to the smoke supplied to the manikins we are able to follow human exhaust. In addition, smoke is added to personal ventilation, so it is possible to check the directions of airflow from diffusers. Both pictures for exhaust and personal ventilation are done one by one, without changing real condition in cabin section.

To be able to get better effect we are presenting result from smoke simulations in pairs: results for the best combination of systems in case of ventilation index (as well as the worst ventilation index) and results for the best combination in case of the best and the worst air quality index.

### 7.3.1. Results for the best combination of systems with reference to ventilation index ($\varepsilon_{exp}$)

The best ventilation index in case of MV+PV system is 1,53, and is obtained for 3 l/s from MV and 12 l/s from PV, (see Chapter 7.2.3), and in case of DV+PV is 5,42, for 5l/s from DV and 15 l/s from PV (Chapter 7.2.4.)

*Figure 7.3.1. Smoke from manikin's mouth. Left: 3 l/s MV + 12 l/s PV ($\varepsilon_{exp}$= 1,53); Right: 5 l/s DV + 15 l/s PV ($\varepsilon_{exp}$= 5,42)*

Figure 7.3.1. shows smoke coming out of the Monkey's mouth in two best cases, if we take ventilation index into consideration. In case of MV+PV, smoke is coming up, taken by relatively strong flow from PV (12 l/s), and than with flow from MV is directed towards corridor. So only a part of exhaust has chance to be inhaled by neighbouring passenger. Plums around passengers' bodies, which are taking part in transporting contaminants, are not disturbed by small flow from MV. Similar situation is in case of DV+PV system (right picture). Stream moves upwards, into exhaust slots, but flow from PV does not let contaminates reach Comfortina's breathing zone. Exhaust mix with air from DV system and is pushed towards outlets.

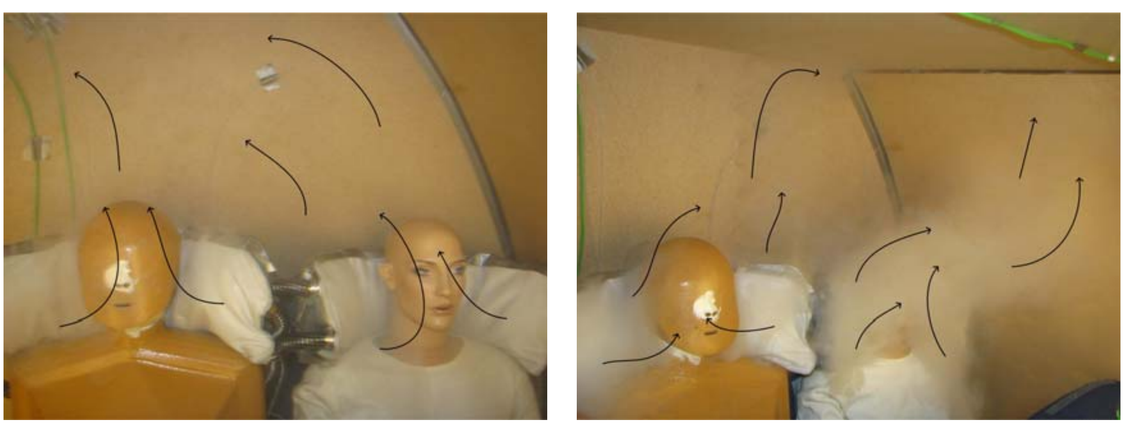


*Figure 7.3.2. Smoke from angled seat cover. Left: 3 l/s MV + 12 l/s PV ($\varepsilon_{exp}$ = 1,53); Right: 5 l/s DV + 15 l/s PV ($\varepsilon_{exp}$ = 5,42)*

Figure 7.3.2. represents smoke coming out from personal ventilation system. In the left picture smoke is coming up, and mixing with air from MV system turns to the left. Right picture shows that supplied air from PV surround manikin's head, gives excellent protection against contaminates from others passengers' exhalations. So the fresh air is constantly delivered to the manikin's breathing zones (that is why the ventilation index reaches 5,42 level).

### 7.3.2. Results for the worst combination of systems with reference to ventilation index ($\varepsilon_{exp}$)

The worst ventilation index in case of MV+PV system is 0,86, and is obtained for 5 l/s from MV and 15 l/s from PV, (see Chapter 7.2.3), and in case of DV+PV is 0,82, for 15l/s from DV and 5 l/s from PV (Chapter 7.2.4.)

*Figure 7.3.3. Smoke from manikin's mouth. Left: 5 l/s MV + 15 l/s PV ($\varepsilon_{exp}$ = 0,86); Right: 15 l/s DV + 5 l/s PV ($\varepsilon_{exp}$ = 0,82)*

Figure 7.3.3. presents smoke simulation for manikin's exhalation for the two worst cases (taking ventilation index into consideration). Smoke, in case of MV+PV, is going upwards and sideways. In case of DV+PV small flow from personal ventilation does not disturb manikin's exhalation and strong flow from DV pushes it towards slots, close to adjacent person. Furthermore, exhalation from manikin's mouth can even reach the breathing zone of passengers sitting in the next row. In both cases ventilation index is unacceptable, on the level of 0,82-0,86.

Photos from Figure 7.3.4. shows smoke coming out form angled seat covers . In case of MV+PV, smoke is going sideways, so contaminants can be pushed to other passengers' breathing zone. Right picture shows flow in case of DV+PV system. Flow from DV is 3 times bigger than from PV, so it pushes smoke towards exhausts slots. In each system airflow from PV diffuser has no clear directivity what causes that passengers in one row have one common breathing zone instead of separated one.

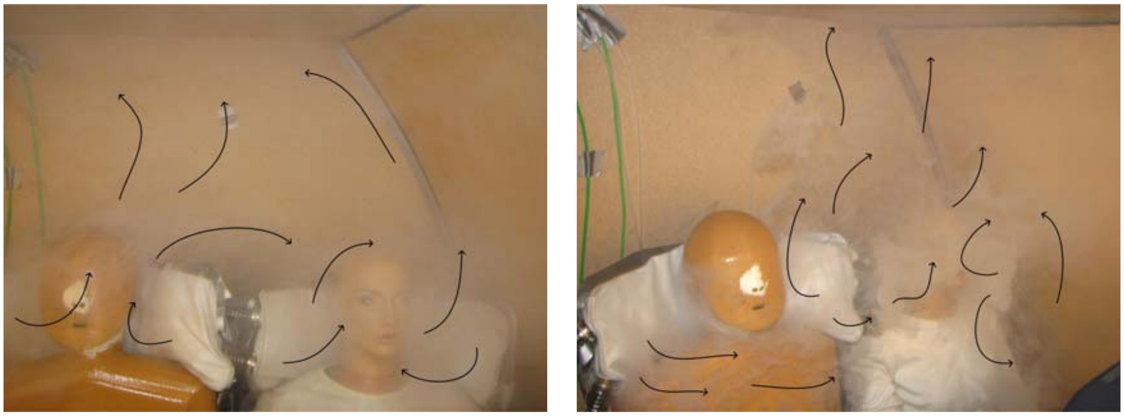


*Figure 7.3.4. Smoke from angled seat cover. Left: 5 l/s MV + 15 l/s PV ($\varepsilon_{exp}$= 0,86); Right: 15 l/s DV + 5 l/s PV ($\varepsilon_{exp}$= 0,82)*

### 7.3.3. Results for the best combination of systems with reference to air quality index ($\varepsilon_{oz}$)

The best air quality index in case of MV+PV system is 1,28, and is obtained for 5 l/s from MV and 5 l/s from PV, (see Chapter 7.2.3), and in case of DV+PV is 0,62, for 15l/s from DV and 5 l/s from PV (Chapter 7.2.4.)

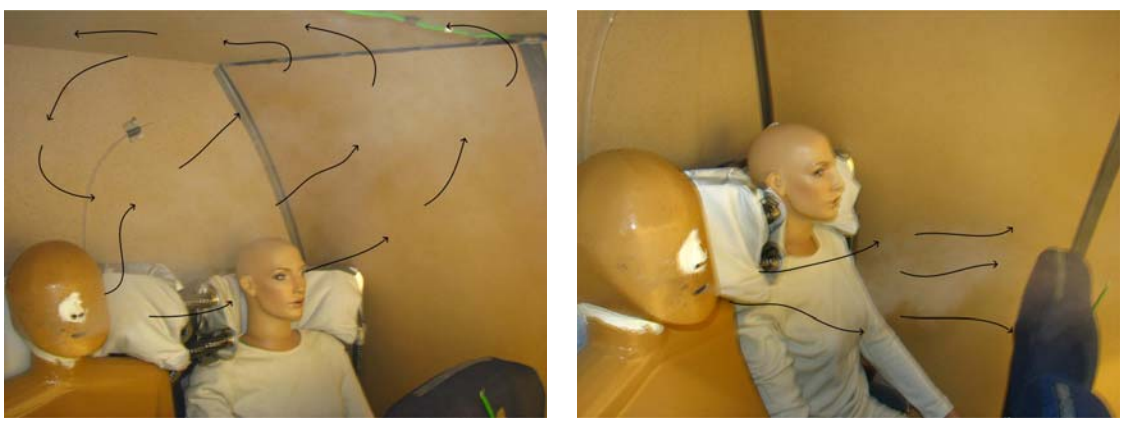


*Figure 7.3.5. Smoke from manikin's mouth. Left: 5 l/s MV + 5 l/s PV ($\varepsilon_{oz}$ = 1,28); Right: 15 l/s DV + 5 l/s PV ($\varepsilon_{oz}$ = 0,62)*

Figure 7.3.5. shows smoke coming out of the Monkey's mouth in two best cases, if we take air quality index into consideration. In case of MV+PV, smoke is coming upward very slowly. Part of contaminants reach breathing zone of other manikin and is inhaled by him. Flow from MV is on 5 l/s level, so does not push much contaminants in to the corridor. Than, supply air makes contaminants colder, so they are transported partly along the ceiling and partly downward, so contaminated air is

not pushed on the high levels of corridor. DV+PV system (right picture) does not provide high air quality index even in its best setup. Stream moves forward, than bands slowly upward towards outlet slots situated on the top of curved wall. Stream moves For this case air quality index is lower than index in case of MV combined with PV, because air in displacements goes from lower parts to higher, and gets stuck in the corridor. It is advised to locate some outlets in corridor to make this index higher.

### 7.3.4. Results for the worst combination of systems with reference to air quality index ($\varepsilon_{oz}$)

The worst air quality index in case of MV+PV system is 0,48, and is obtained for 5 l/s from MV and 15 l/s from PV, (see Chapter 7.2.3), and in case of DV+PV is 0,36, for 10l/s from DV and 10 l/s from PV (Chapter 7.2.4.)

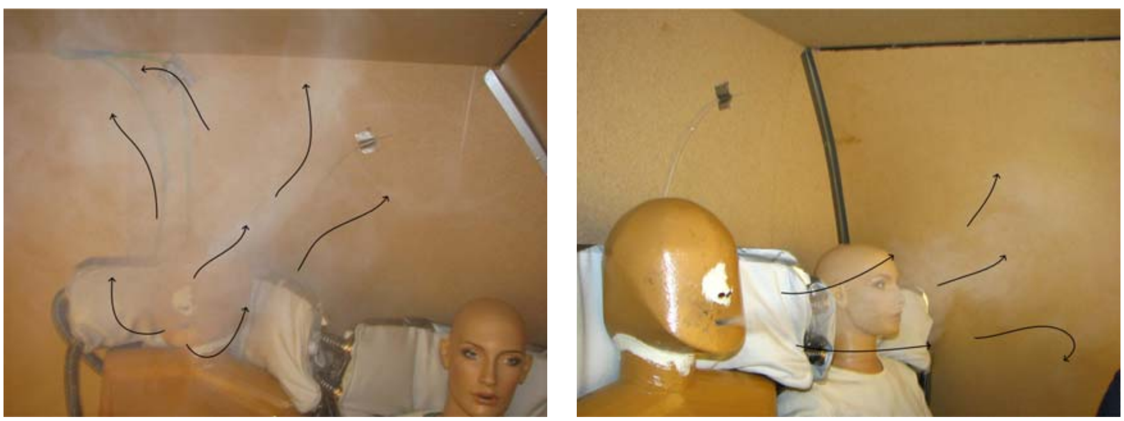


*Figure 7.3.6. Smoke from manikin's mouth. Left: 5 l/s MV + 15 l/s PV ($\varepsilon_{oz}$ = 0,48); Right: 10 l/s DV +105 l/s PV ($\varepsilon_{oz}$ = 0,36)*

Figure 7.3.6. shows smoke coming from manikin's mouth for the worst cases, in case of air quality index. Strong flow from personal ventilation in MV+PV system pushes exhaust upwards. Low airflow from upper nozzle (5 l/s) is not sufficient enough to cool down all warm contaminations because they are moving with to high velocity. However, even small airflow from MV diffuser cause airflow along the ceiling. Thus mixture is directed towards corridor, where stewardess might stay. That is why air quality index is very small over there.

The air quality index for the worst DV+PV setup is equal 0,36 but actually the value is similar to the best case (0,62) what means that contaminants will spread towards corridor in similar way. In case of DV+PV system exhalation is pushed towards outlets, but still some part has chance to get to corridor sector, where can get stuck.

### 7.3.5. Summary

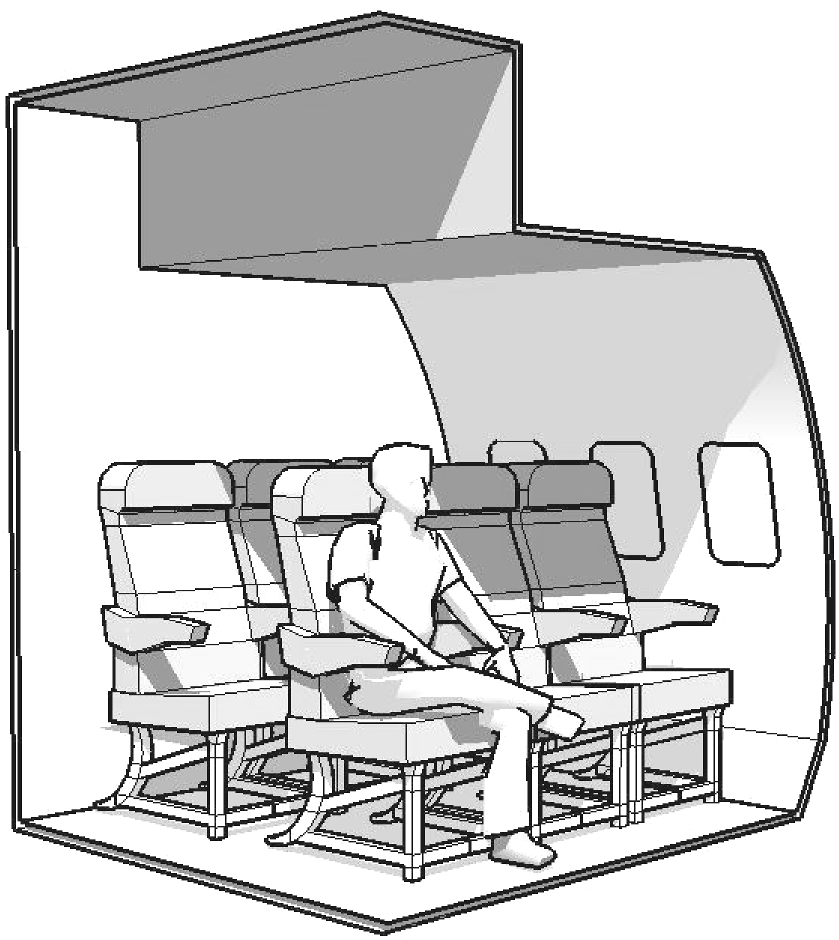
Smoke helps to visualize what is happening inside cabin section. Thanks to that, we are able to follow airflows both from personal ventilation system and exhalation from Monkey’s mouth. In case of Mixing Ventilation combined with Personal Ventilation, the worst set up is 5 l/s from MV and 15 l/s from PV. This configuration has the worst ventilation index as well as air quality index. In case of Displacement Ventilation, configuration 15 l/s from DV and 5 l/s from PV has the worst ventilation index, but on the other hand, has the best air quality index.
Due to that fact, it is advised in further research to focus on improvements in DV system, such as better inlets, extra outlets in corridor, etc.

***Bibliography:***


- [1] E. Barszcz, T. Czarnota, D. Dymalski, M. Jasieński, A. Mozer, A. Nowotka, S. Wiankowska “New Solution for Personalized Ventilation in Aircrafts. Textile Ventilating Surfaces”. Aalborg University 2007

# 8.CHAPTER

# CFD SIMULATIONS



Computational Fluid Dynamics is a computer based model which is able to predict air movement, temperature and contaminant distribution, as well as many other parameters of room air distribution. This prediction is based on a solution of fundamental flow equations (continuity, three momentum, the energy and the transport equations).
The development of CFD models for room air movement is strongly influenced by the increased computer power. Because of that fact, CFD calculations have rapidly become a powerful tool for the analysis of air and pollution distribution in various spaces. However, the reliability of the results depends mostly on the skills of the person who performs the calculations.
To perform simulations in our project we are using British program FloVent, version 6.1. and 7.2. [1]

## *8.1. Description of model*

CFD simulations cover only cabin section model. Wind tunnel simulations were conducted in last semester project [2].

### 8.1.1. Dimensions

Cabin section model used in CFD is simplified. It doesn't have curved wall like in laboratory measurements. It has box shape with walls size of 177 x 81 x 168 cm. Inlet has similar size like in reality (0,4 cm x 81 cm), but outlet, instead of 10 round wholes, is a 4 cm x 81 cm rectangular.

Seat used in simulation has simplified shape as well.

### 8.1.2. Airflow

All simulations are performed in steady airflow conditions. Mixing and Displacement Ventilation have 20 l/s in inlet and 20 l/s in outlet. Temperature of supplying air is calculated from the equation [6.6] from Chapter 6.3.3.

In case of combining Personal with Mixing and Displacement Ventilation, inflow to cabin is on level of 10 l/s, airflow from PV 10 l/s (divided on to diffusers), and outlet from model is 20 l/s.

## 8.2. Description of used CFD manikins.

### 8.2.1. Dimensions of manikins' body elements.

To better simulate manikins in FloVent, their 'body' is divided into 6 parts: head, torso, upper legs and shins. Comfortina as well as Monkey are represented by the same twin CFD equivalents. Both of them have a complex body structure, as it is necessary to perform right CFD simulations [2].

Description of used manikin is given below:

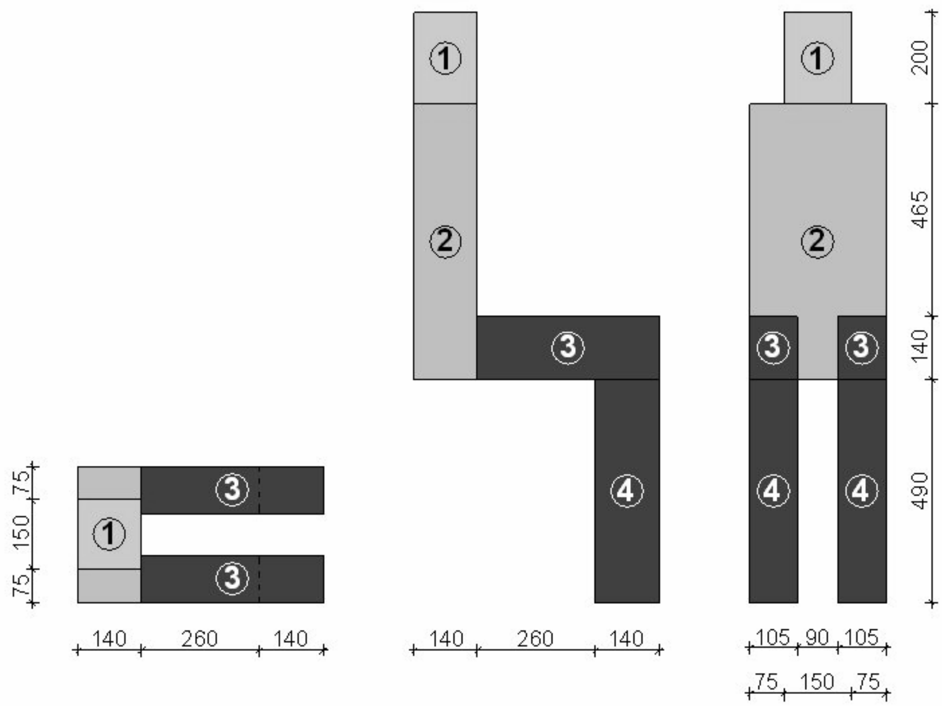



*Figure 8.3 . Dimensions and numeration manikin's body parts.[2]*

Numbers stand for: 1- head, 2- torso, 3- upper leg, 4- shin.
Shape and dimensions used in the simulations are the same like in last years' projects [2], [3], [5].

### 8.2.2. Heat load

Total heat emitted from the manikins is comparable with the heat emission represented by a woman with low activity level (80 W – radiation 50% and convection 50%). However, radiation is not taken into consideration, thus total heat emission from sitting manikin is reduced from 2x80W to 2x40W.

Heat output from the human body is related to its capacity and is rather constant, total heat outputs are divide on individual parts of simulated manikins. Heat outputs we are using in models base on heat outputs used in “Ventilating Textile Surfaces. A new approach to Personalized Ventilation” report. [5]

| Part of body (one manikin) | Dimensions [m*m*m] | Capacity [$m^3$] | Total heat output [W] | Heat output per capacity [$W/m^3$] |
|---|---|---|---|---|
| Head | 0.14x0.20x0.15 | 0.0042 | 2.8 | 666.7 |
| Torso | 0.14x0.605x0.30 | 0.0254 | 21.6 | 850.4 |
| Upper legs | 0.40x0.14x0.105 | 2 x 0.0059 | 2 x 3.6 | 610.2 |
| Shins | 0.14x0.49x0.105 | 2 x 0.0072 | 2 x 4.0 | 555.6 |

*Table 8.2. Specification of total heat outputs from individual parts of the human body (per manikin).*

## 8.3. Conception of the angle seat cover

### 8.3.1. Airflow from head rest

Digital diffuser consist form three parts. Total airflow is set as 5 l/s (per whole diffuser). The temperature of supplied air is 23°C (like temperature inside cabin section model).

### 8.3.2. Dimensions

Construction of the diffusers differs from that one used in previous projects [2], [5]. Model used in FloVent is very simplified (due to program restrictions). To better reflect real outflow, back part was extinguished from 250 mm to 470 mm, and sides trimmed from 200 to 14,5 mm. However, air from that seat cover flows as the same angle as it is in real (45° from side parts, and 90° from back part). Figure 8.4. shows this conception in details.

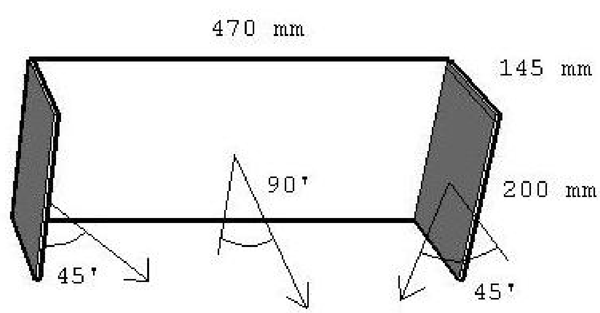



*Figure 8.4. Dimensions of the angle seat cover used in CFD simulations.*

## 8.4. CFD Setup

### 8.4.1. Modeling.

In CFD simulations application with three dimensional flow is used. To assure high similarity in comparison with full-scale experiment, airflow with heat transfer function is chosen. Radiation is not taken into consideration. To perform simulations that show concentration distribution in the wind channel concentration function is on. Neck supporter is supplied with air with tracer gas in concentration of 150 ppm Mentioned level is similar to values measured in full-scale experiments for 10dm$^3$/s airflow from the neck supporter.

### 8.4.2. FloVent setup.

One of the most important things is choosing the most appropriate turbulence model. The most common turbulence model is k- ε. Here transport equations are solved for the turbulent kinetic energy, k, and its dissipation, ε. This model is used in our simulations. [1]

Ambience conditions inside and outside the simulated cabin section are the same. Table 8.4. shows the most important parameters:

| *Parameters* | *Value* |
|---|---|
| Pressure | 1 Atm |
| Radiant temperature | 23 oC |
| Ambient temperature | 23 oC |
| Specific heat | 1.005 J/kg·K |
| Expansivity | 3.33 ·10-3 1/K |
| Density | 1,19 kg/m3 |
| Humidity | 50 % |
| Conductivity | 2.61·10-2 W/m*K |
| Viscosity | 1.84·10-5 N*s/m2 |
| Diffusivity in Primary Fluid | 1.84·10-5 m2/s |

*Table 8.4. Parameters of air used in CFD simulations.*

Value of kinetic energy of turbulence and dissipation rate of turbulence for flow in inlet, outlet and angled seat covers are calculated according to equation shown below:

$$kinetic\ energy\ of\ turbulence = 10^{-3} \cdot [velocity]^2$$

$$dissipation\ rate\ of\ turbulence = \frac{0.1643 \cdot \left[10^{-3} \cdot (velocity)^2\right]^{\frac{3}{2}}}{l_i}$$

$$l_i = 0.1 \cdot (inlet\ area)^{\frac{1}{2}}$$

## *8.5. Grid dependence*

To solve these differential equations it is necessary to apply numerical methods. Our model is divided into grid points. Equations are transformed into discretization form formed around each grid point. So the number of cells (grids) used in CFD simulations has a direct impact on the accuracy of obtained results. [1]

“Ideally, all solution presented from CFD studies should be independent of the computational grid, meaning that the solutions will not change if the computational grid is further refined. Unfortunately, because of restrictions in computer power and time, obtaining a grid-independent solution is almost impossible – at least for three-dimensional calculations.
Obtaining grid - convergence implies that the solution asymptotically approaches the exact solution (to the governing equations). Thus it is expected that a further refinement of the computational grid will change the solution, but not significantly.” [Sørensen & Nielsen, 2003]

To determine accurate number of grid, nine different grids (finer and more coarse) are applied for the same setup. Monitor points are used to check temperature, concentration of $N_2O$ and x velocity values in three representative points: outlet, Monkey’s nose and in the point where anemometer is (in case of mixing ventilation system). These monitor points are chosen because they are situated in three different places and on three different highs in the cabin section. Furthermore, these points have their equivalent sensors in the cabin section.

The following table shows results from Flovent software for steady-state solution.

| *Grid* | *Monitor point* | *Temperature* | *$N_2O$ concentration* |
|---|---|---|---|
| *[cell]* | *[-]* | *[°C]* | *[ppm]* |
| 27 840 | anemometer | 23,03 | 0,059 |
| | Monkey’s nose | 23,75 | 0,075 |
| | outlet | 23,19 | 0,063 |

| | | | |
|---|---|---|---|
| 47 520 | anemometer | 23,17 | 0,060 |
| | Monkey's nose | 23,72 | 0,075 |
| | outlet | 23,21 | 0,075 |
| 71 340 | anemometer | 23,03 | 0,059 |
| | Monkey's nose | 23,75 | 0,075 |
| | outlet | 23,19 | 0,075 |
| 101 660 | anemometer | 23,03 | 0,059 |
| | Monkey's nose | 23,75 | 0,075 |
| | outlet | 23,20 | 0,075 |
| 139 230 | anemometer | 23,03 | 0,059 |
| | Monkey's nose | 23,75 | 0,075 |
| | outlet | 23,19 | 0,075 |
| 224 175 | anemometer | 23,02 | 0,057 |
| | Monkey's nose | 23,76 | 0,074 |
| | outlet | 23,19 | 0,075 |
| 339 840 | anemometer | 23,15 | 0,072 |
| | Monkey's nose | 24,03 | 0,078 |
| | outlet | 23,20 | 0,075 |
| 512 000 | anemometer | 23,16 | 0,070 |
| | Monkey's nose | 24 | 0,078 |
| | outlet | 23,18 | 0,075 |
| 729 000 | anemometer | 23,16 | 0,072 |
| | Monkey's nose | 24,01 | 0,079 |
| | outlet | 23,17 | 0,075 |

*Table 8.6.1. Results from monitor points*

For further CFD calculations 339 840 cells are chosen because, for parameters important to project, increasing number of grids do not provide more accuracy.

Detailed specification of whole grid:

- Number of grid in x direction: 72
- Number of grid in y direction: 80
- Number of grid in z direction: 59
- The smallest grid cell in x direction: 0,015 m
- The smallest grid cell in y direction: 0,001 m
- The smallest grid cell in z direction: 0,0099 m

Above numbers cover all grid, also additional grid cells which are added near diffusers. Detailed grid distribution is shown in each view in figure below.

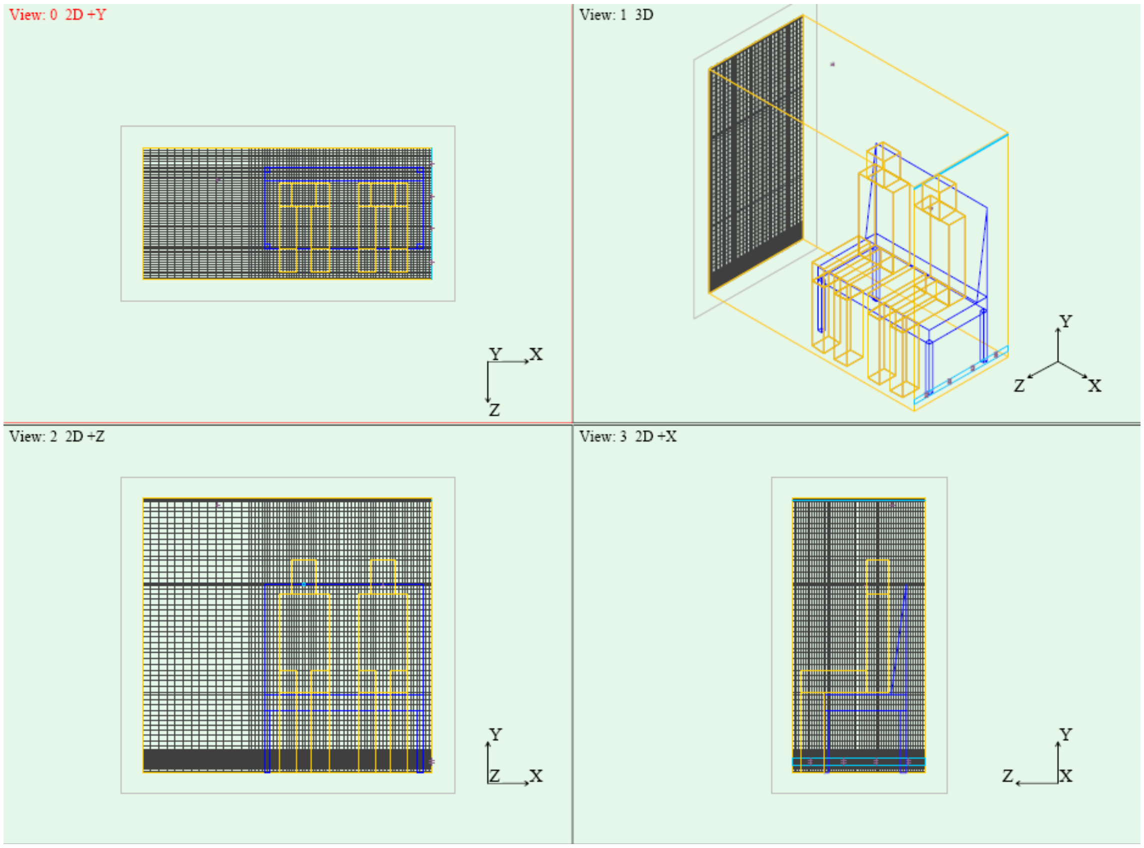



*Figure 8.6.1. View of grid used in simulation*

## 8.6. Results for mixing and displacement ventilation in cabin section

Beside general assumption, both simulations are made for the following parameters:

- supply from inlet 20 l/s
- exhaust from outlet 20 l/s
- each distribution is shown in the same section in axis z=0,36m, y=1,15m and z=1,47m what refers to Monkey's nose

Table below shows results from CFD simulations in comparison with real values from measurements from the same points. Temperature is not taken into consideration because different temperatures are supplied to CFD model and different in reality.

| *Item* | *MV* | | *DV* | |
|---|---|---|---|---|
| | *CFD* | *Measurements* | *CFD* | *Measurements* |
| Maximal velocity $v_{max}$ | 0,978 m/s | 0,579 m/s | 0,575 m/s | 0,972 m/s |
| Ventilation index $\varepsilon_p$ | 1,01 | 0,94 | 0,97 | 0,86 |

*Table 8.6.1. Results from CFD simulations and real measurements for MV and DV*

## Temperature distribution

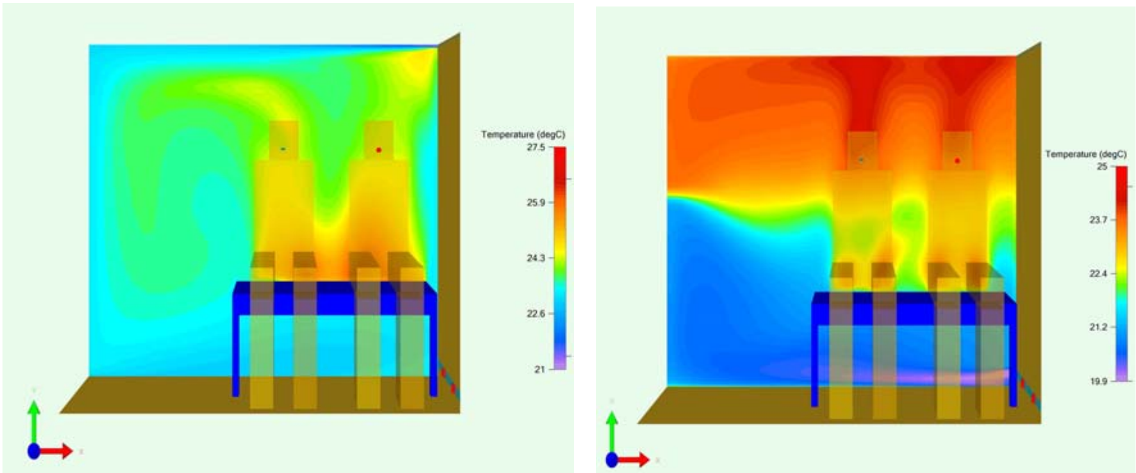



*Figure 8.7.1. Temperature distribution in axis z=0,36m; left for MV, right for DV*

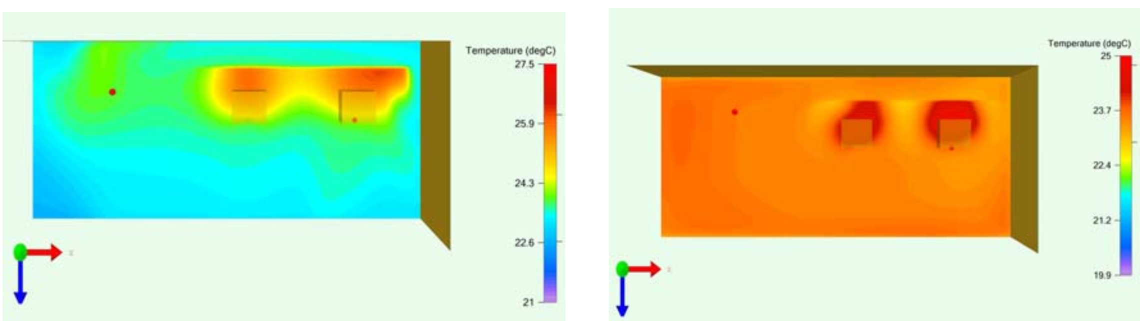



*Figure 8.7.2. Temperature distribution in axis y=1,15m; left for MV, right for* DV

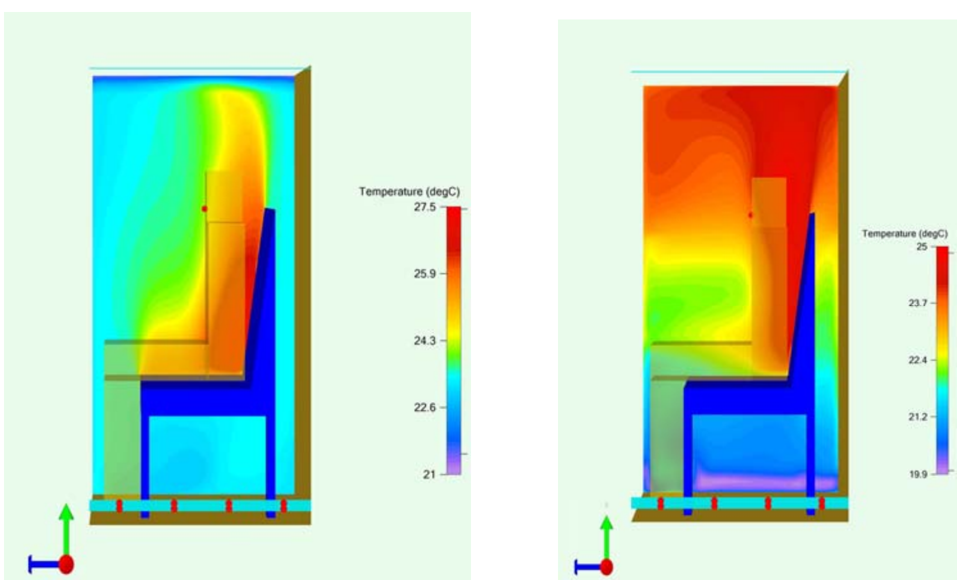


*Figure 8.7.3. Temperature distribution in axis x=1,47m; left for MV, right for DV*

Figures above shows three views on temperature distribution in cabin section. Manikins represent human with low level activity. In both cases free convection flows around the manikins (heat sources) are visible.

In case of mixing ventilation, these plums are going upwards like in reality and they are turning left when they reach stream from upper nozzle. Furthermore, supply air cools warm plumes which finally turn round near left wall. Convection flow from right manikin is going nearly straight up because there is low velocity area in x-direction above his head so airflow is not disturbed.

In case of displacement ventilation warm contaminants are going up with convection flows. But in contrast to mixing ventilation they are exhausting by upper nozzle and partly spreading along the ceiling. Low temperature is noticed below the airplane seat and close to legs because air supplied from lower nozzle is colder than surroundings. This cold stream causes local discomfort.

## Velocity distribution

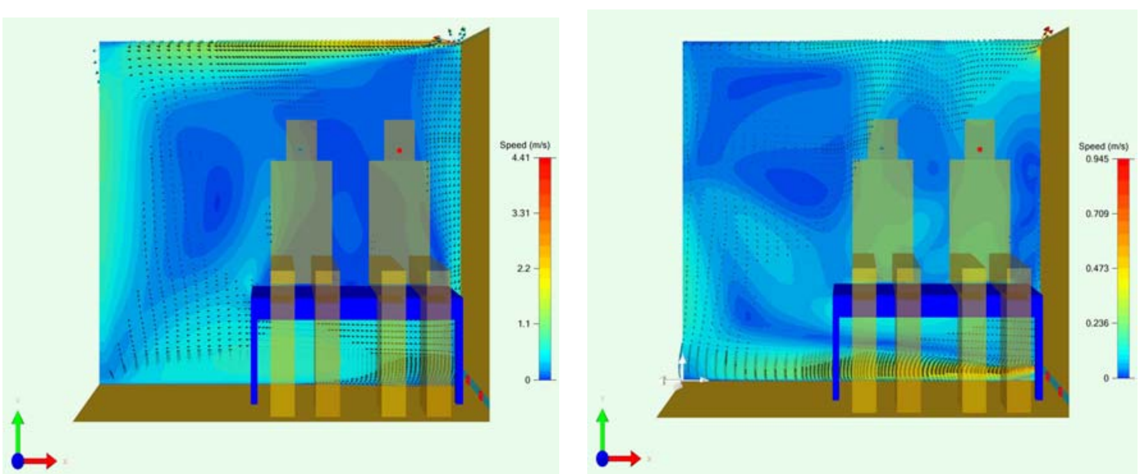



*Figure 8.7.4. Velocity distribution in axis z=0,36m; left for MV, right for DV*

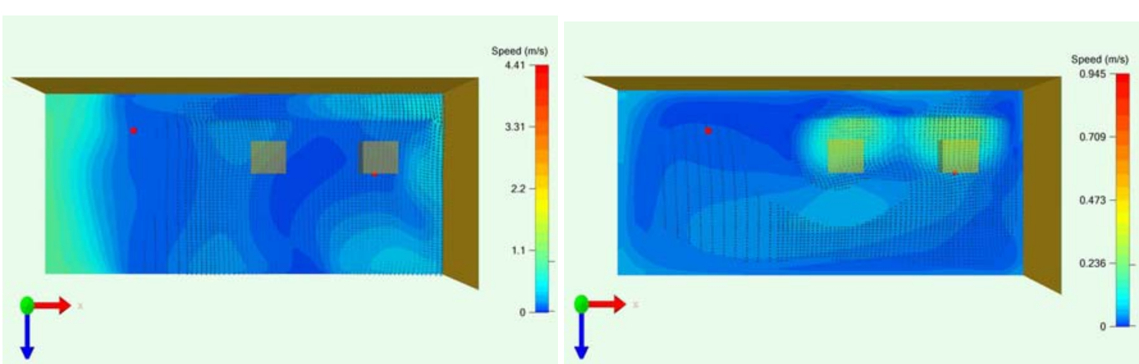



*Figure 8.7.5. Velocity distribution in axis y=1,15m; left for MV, right for DV*

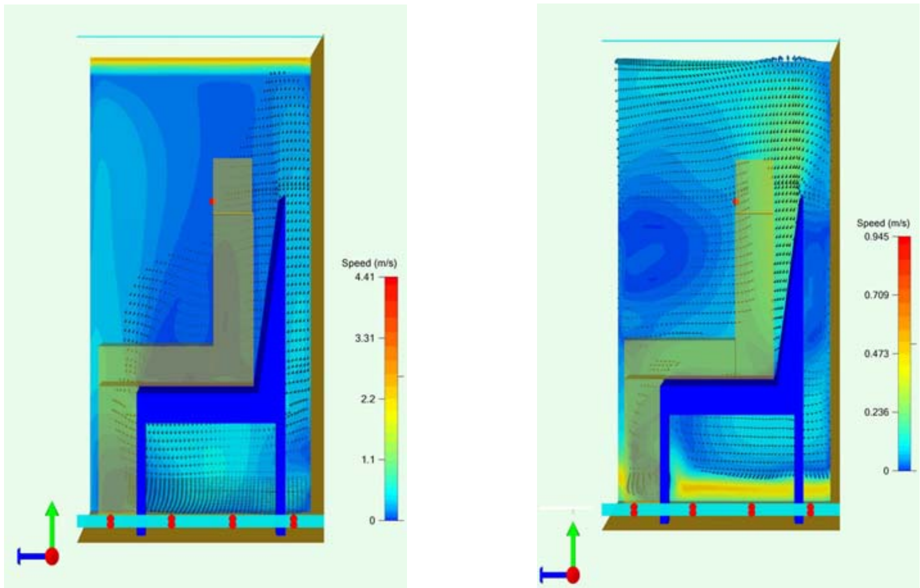



*Figure 8.7.6. Velocity distribution in axis x=1,47m; left for MV, right for DV*

In case of mixing ventilation, the highest speed is few centimeters below the ceiling, as it is in reality. Low velocity area above the right manikin is caused by influence of second manikin, who seats very close. In this way, convection flows connect into one vertical airflow with small velocity. Generally, supply air goes along the ceiling, turns down along the wall, and goes towards the exhaust behind the airplane seat.

In displacement ventilation plums from manikins (heat sources) are coming upward until they reach ceiling. Then part of airflow is blown outside the model and the rest of it turn left towards the wall. Warm air loses a part of heat on the way to left wall and it is displaced downwardly with minimal velocity.
High velocity directs cold stream of supply air towards the wall where is becomes to go upwardly. Approximately 90 cm above the floor cold air meets with warm air and this mixed air goes towards the manikins.

## Contaminants distribution

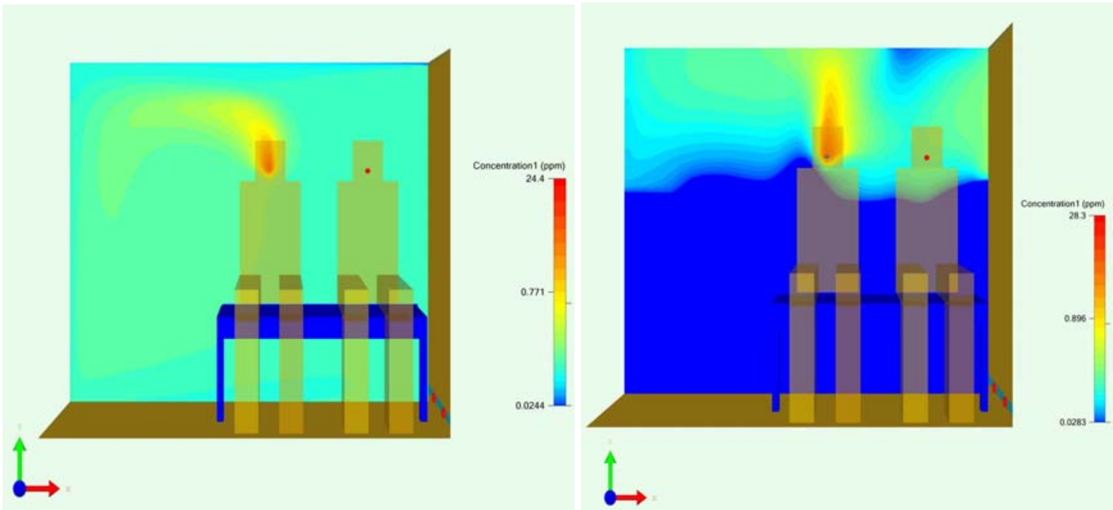



*Figure 8.7.7. Contaminants distribution in axis z=0,36m; left for MV, right for DV*

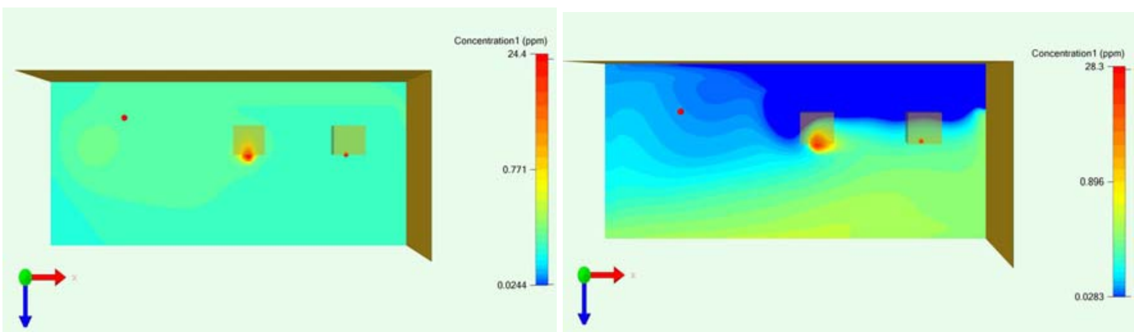



*Figure 8.7.8. Contaminants distribution in axis y=1,15m; left for MV, right for DV*

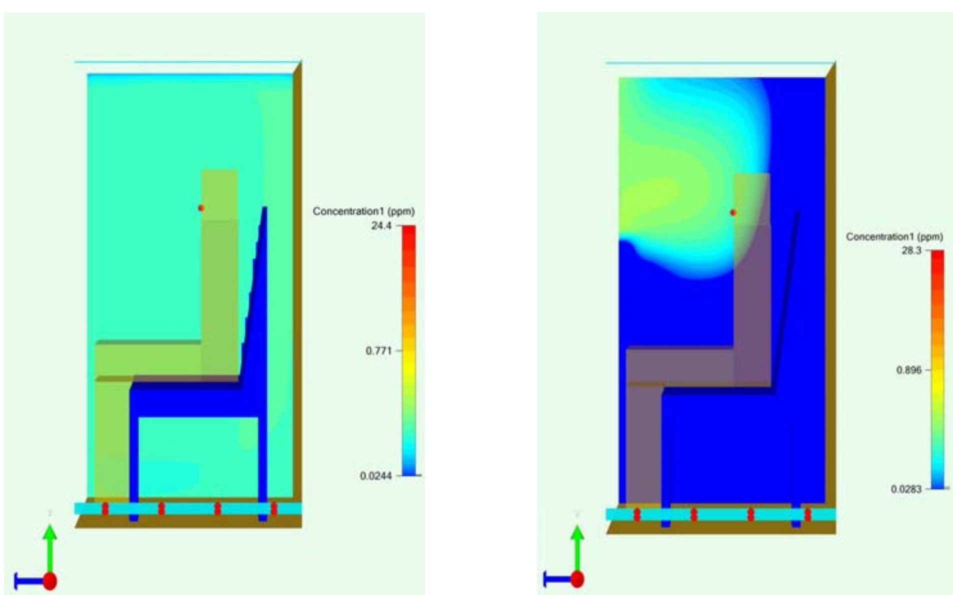



*Figure 8.7.9. Contaminants distribution in axis x=1,47m; left for MV, right for DV*

For better view in each figure, $N_2O$ concentration is shown in log scale. Ventilation index for mixing ventilation is higher in CFD, as well as in measurements, than for displacement ventilation respectively. It is also visible in figures above. Contaminants exhaled by left manikin (Comfortina) are blown away from breathing zone and they are diluted in whole cabin section when mixing ventilation is provided with personal ventilation system.

Completely different situation is observed if displacement ventilation is combined with personal ventilation system. As it is shown in right pictures above, contaminants are spread only above the manikins' heads. Furthermore, concentration of $N_2O$ is close to zero behind the aircraft seat, what means that in this setup passengers sitting behind the sick person are not in risk from health point of view.

## 8.7. Results for both types of combined ventilation in cabin section (10MV+10PV and 10DV+10PV)

Beside general assumption both simulations are made for the following parameters:

- supply from inlet 10 l/s
- supply from PV diffuser 10 l/s
- exhaust from outlet 20 l/s
- each distribution is shown in the same section in axis z=0,36m, y=1,15m and z=1,47m what refers to Monkey's nose

| *Item* | *MV* | | *DV* | |
|---|---|---|---|---|
| | *CFD* | *Measurements* | *CFD* | *Measurements* |
| Maximal velocity $v_{max}$ | 0,321 m/s | 0,210 m/s | 0,291 m/s | 0,935 m/s |
| Ventilation index $\varepsilon_p$ | 1,058 | 0,9 | 0,66 | 1,57 |

*Table 8.7.1. Results from CFD simulations and real measurements for 10MV+10PV and 10DV+10PV*

## Temperature distribution

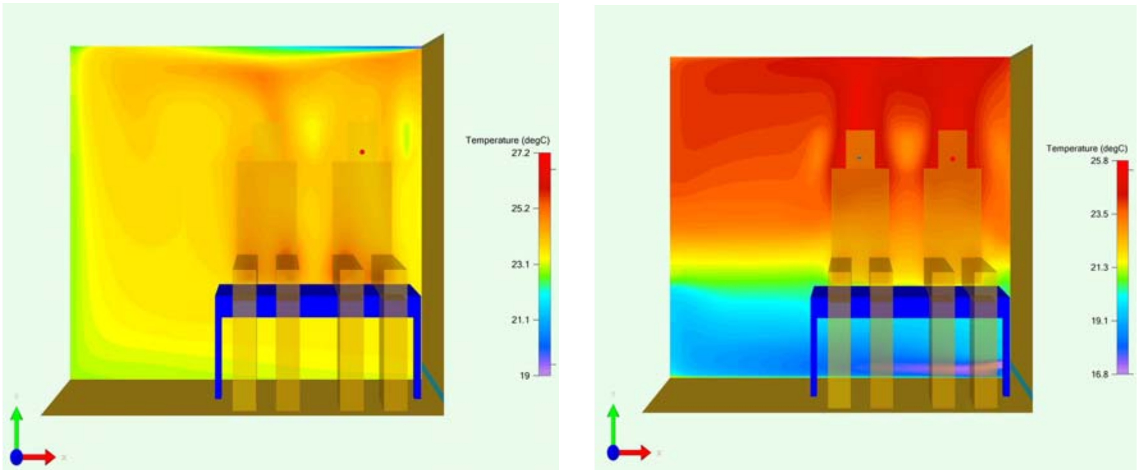



*Figure 8.7.1. Temperature distribution in axis z=0,36m; left for 10MV+10PV, right for 10DV+10PV*

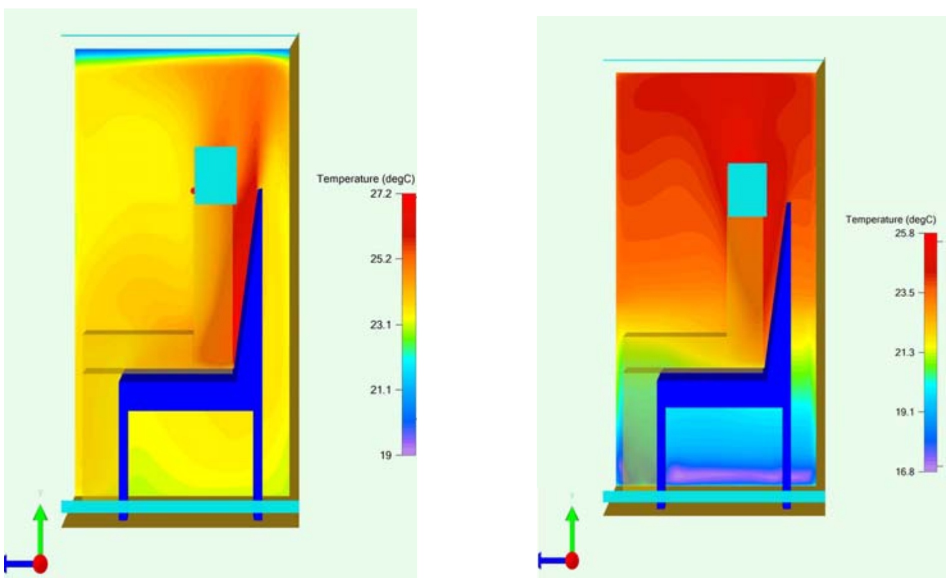



*Figure 8.7.2. Temperature distribution in axis x=1,47m; left for 10MV+10PV, right for 10DV+10PV*

In case of MV plus PV system temperature distribution is more uniform in whole cabin section than in case of single mixing ventilation. PV diffuser added to the system generate velocity in front of manikin which in combination with cold supply air cool the air in front of manikins. In the same time, warming air behind the manikins is caused by free convection flow.
According to displacement ventilation, PV diffuser added to the system and heat generated from manikins causes that higher temperature appears on lower level than in case of single displacement ventilation.

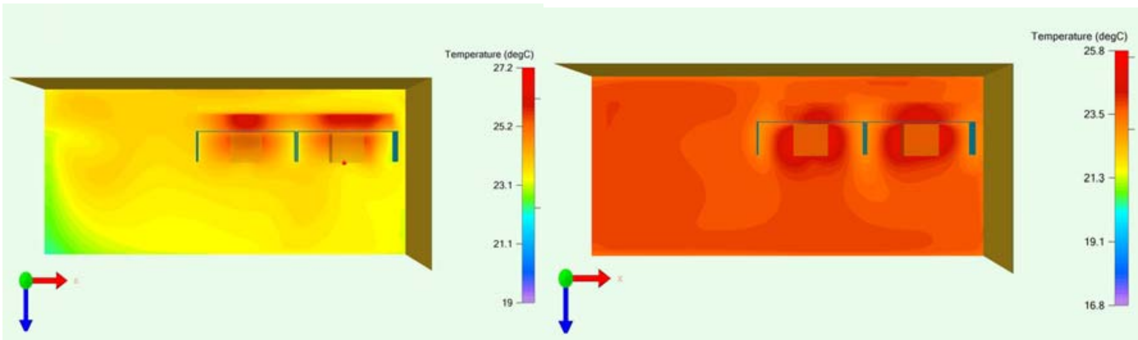



*Figure 8.7.3. Temperature distribution in axis y=1,15m; left for 10MV+10PV, right for 10DV+10PV*

## Velocity distribution

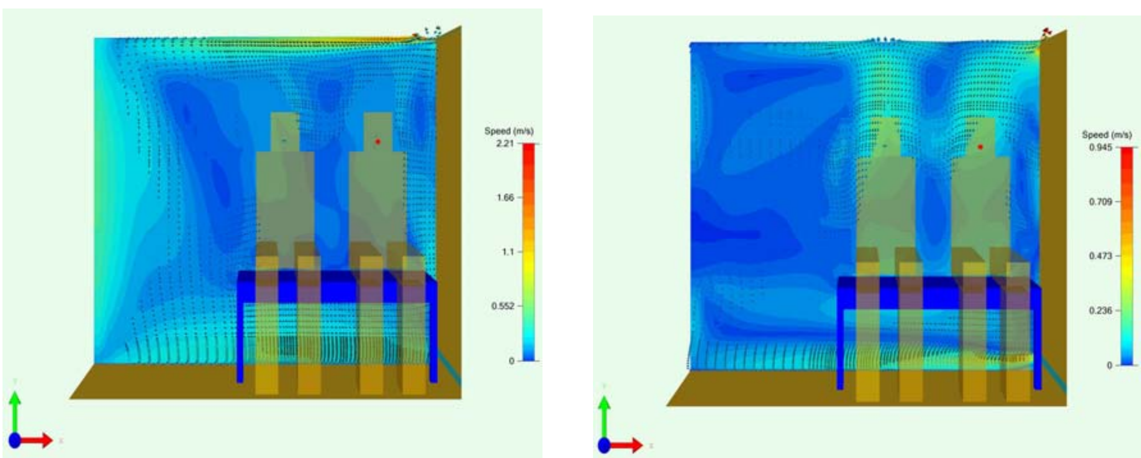



*Figure 8.7.4. Velocity distribution in axis z=0,36m; left for 10MV+10PV, right for 10DV+10PV*

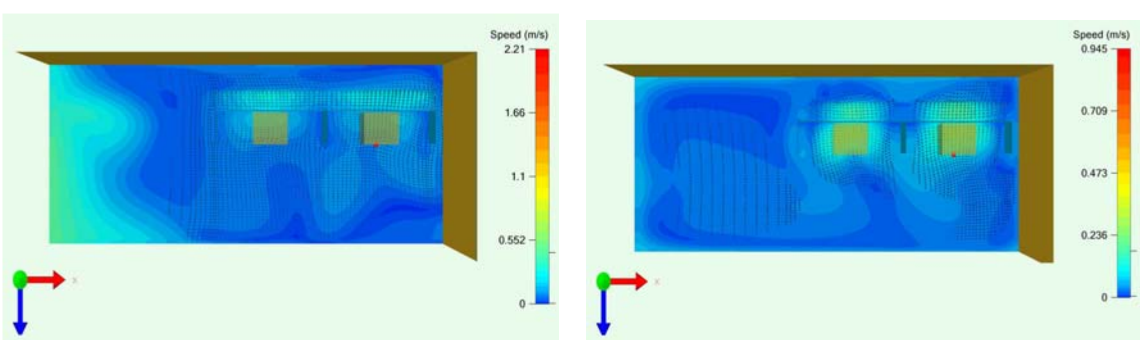



*Figure 8.7.5. Velocity distribution in axis y=1,15m; left for 10MV+10PV, right for 10DV+10PV*

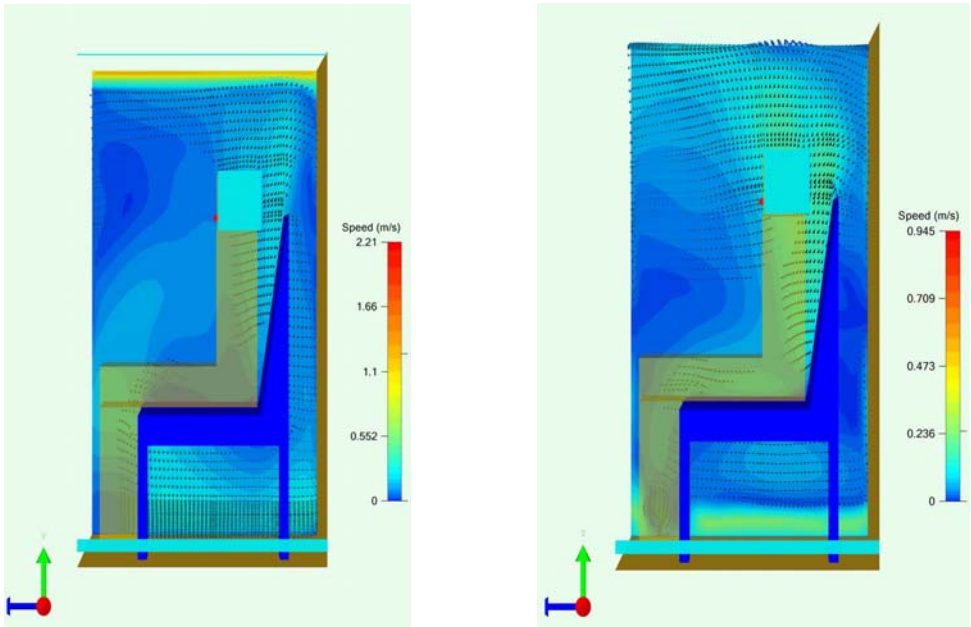



*Figure 8.7.6. Velocity distribution in axis x=1,47m; left for 10MV+10PV, right for 10DV+10PV*

In case of mixing ventilation, the highest speed is few centimeters below the ceiling, as it is in previous simulations. Supplying air is disturbed by airflow from personal diffuser, and convection flows. Supply air turns down along the wall, and than turns heading outlet. In that place velocity of air is higher than other places as well.

In displacement ventilation plums from manikins (heat sources) are coming upward until they reach ceiling. Plums mix with air from personal ventilation, so speed is higher than in other places. When air is reaching ceiling, it starts to turn towards outlet slots.

## Contaminants distribution

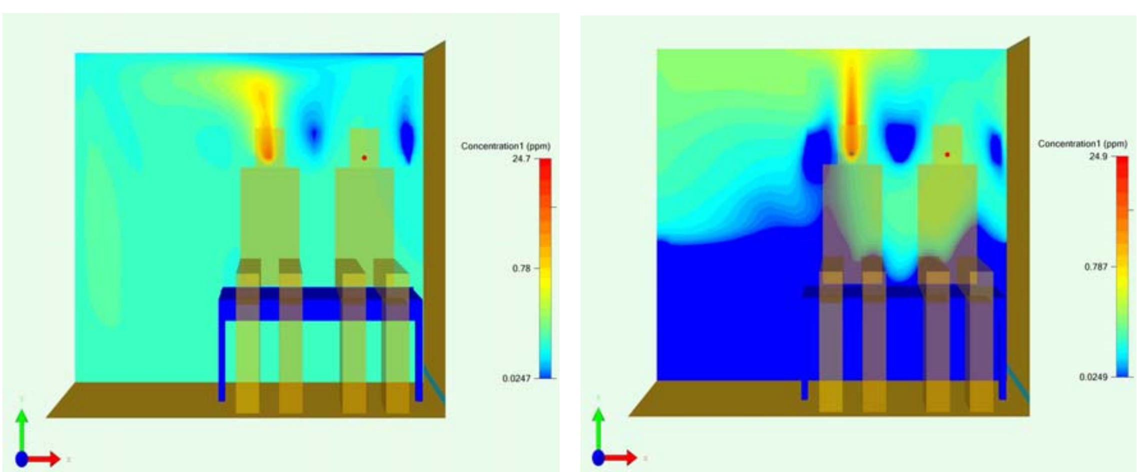



*Figure 8.7.7. Contaminants distribution in axis z=0,36m; left for 10MV+10PV, right for 10DV+10PV*

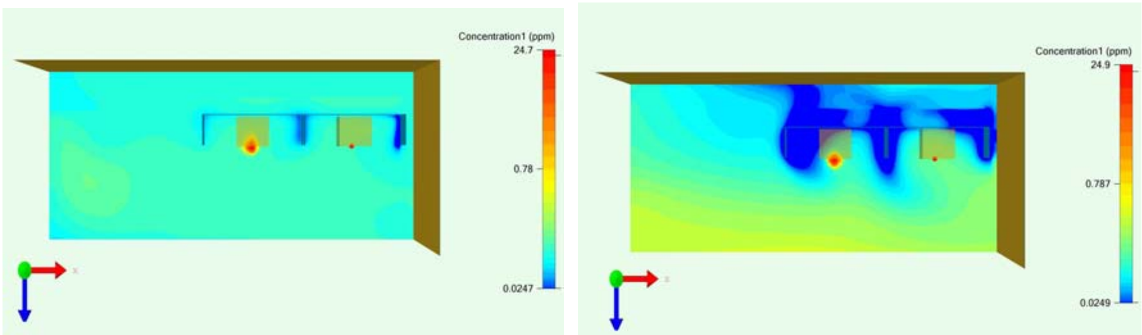



*Figure 8.7.8. Contaminants distribution in axis y=1,15m; left for 10MV+10PV, right for 10DV+10PV*

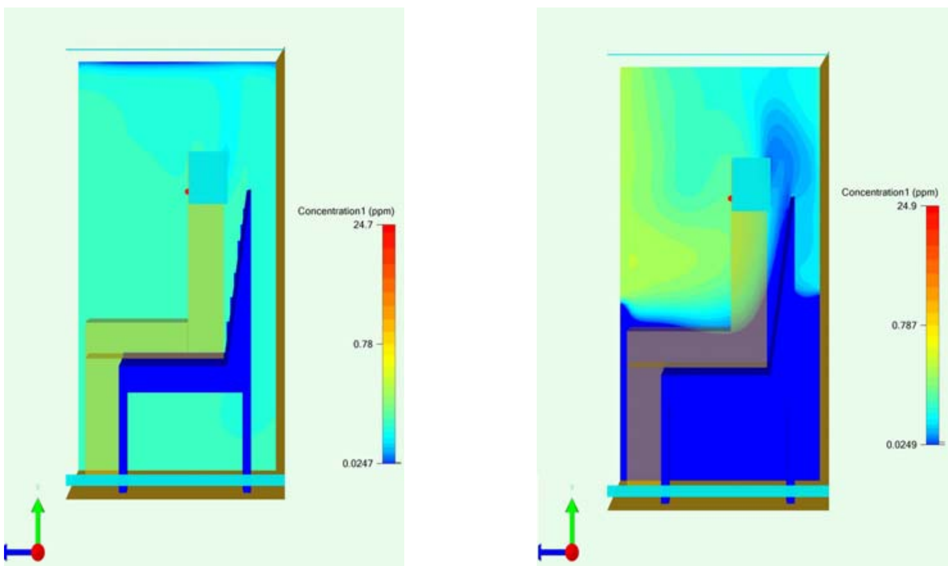



*Figure 8.7.9. Contaminants distribution in axis x=1,47m; left for 10MV+10PV, right for 10DV+10PV*

For better view in each figure, $N_2O$ concentration is shown in log scale. Ventilation index for mixing ventilation combine with personal ventilation system counted from CFD simulation is comparable with its digital equivalent. However results for DV plus PV system are more than twice different.

Contaminants exhale by left manikin (Comfortina) go upwardly from the breathing zone. Air supplied from upper nozzle connects with warm contaminants and dilutes them by spreading in the cabin section. Thus, it is nearly uniform concentration level in whole model.

Contaminants distribution for 10 l/s from DV and 10 l/s from PV is similar to situation observed in displacement ventilation. As it is shown in right pictures above contaminants are spread mostly above the manikins' heads. But in contrast to only DV they are spread behind the aircraft seat. Moreover, passengers and stewardesses in the corridor are also in risk as the high concentration level is noted there.

## *8.8. Additional results for both types of combined ventilation in cabin section*

The key case of this project is not a CFD simulation, thus model used in FloVent is very simplified. Computational Fluid Dynamics is used to predict air movement and contamination distributions, and consider its results as an independent source of information, which made comparison with laboratory measurement very valuable.

The other combination of system are not taken into consideration as a separate simulation, because simplifications make results differ from real measurements, as well as make almost impossible to show detailed differences between particular ventilation setups. It happens because ambient conditions in CFD are ideal, and those in laboratory just tends to be ideal, steady and constant in time. Shapes of manikins are simplified in CFD in comparison to the real ones as well. Comfortina is not as high as other one is, so containments, in case of DV, might go upwards toward Monkey. In addition, MV outlets (DV inlets) are represented by digital slot, while there are 10 round holes in reality. Similarly, in CFD outside wall is simply vertical, but in laboratory has original, round shape. All those factors have impact on simulations' results.

Tables below prove the difference between real measurements and their digital equivalents.

| *Item* | *3MV + 12 PV* | | *5DV + 15PV* | |
|---|---|---|---|---|
| | *CFD* | *Measurements* | *CFD* | *Measurements* |
| Maximal velocity $v_{max}$ | 0,104 m/s | 0,159 m/s | 0,142 m/s | 0,43 m/s |
| Ventilation index $\varepsilon_p$ | 1,86 | 1,53 | 0,87 | 5,42 |

*Table 8.8.1. Results from CFD simulations and real measurements for 3MV+12PV and 5DV+15PV*

| *Item* | *5MV+15PV* | | *15DV+5PV* | |
|---|---|---|---|---|
| | *CFD* | *Measurements* | *CFD* | *Measurements* |
| Maximal velocity $v_{max}$ | 0,169 m/s | 0,198 m/s | 0,424 m/s | 0,982 m/s |
| Ventilation index $\varepsilon_p$ | 1,54 | 0,86 | 11,67 | 0,82 |

*Table 8.8.2. Results from CFD simulations and real measurements for 5MV+15PV and 15DV+5PV*

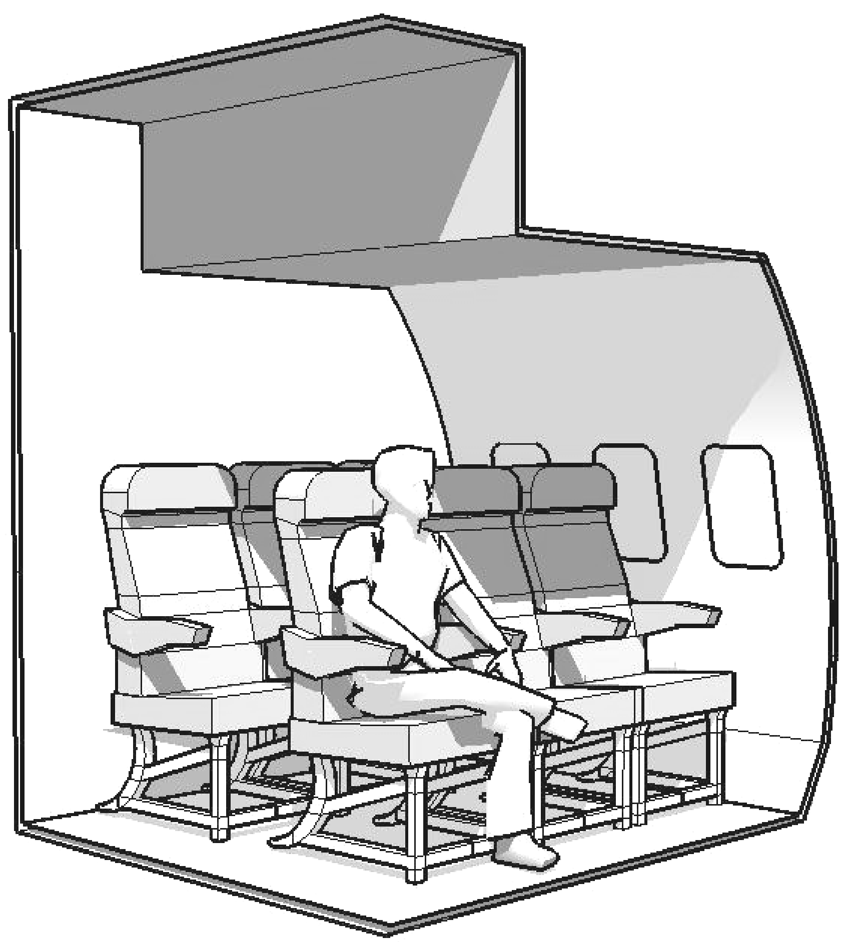
.

## ***Bibliography:***


- [1] Peter V. Nielsen, Francis Allard, Hazim B. Abwi, Lars Davidson, Alois Schälin, "Computational Fluid Dynamics in Ventilation Design" REHVA GUIDEBOOK No 10, Forssa, Finland, Rehva, 2007
- [2] E. Barszcz, T. Czarnota, D. Dymalski, M. Jasieński, A. Mozer, A. Nowotka, S. Wiankowska, "New solution for Personalized Ventilation in Aircrafts. Ventilating textile Surfaces" Aalborg University 2007,
- [3] Henrik Brohus, "Personal Exposure to Contaminant Sources in Ventilated Rooms", Ph.D.-Thesis,1997, Aalborg University, Denmark.
- [4] Zdzisław Orzechowski, Jerzy Prywer, Roman Zarzycki, "Mechanika płynów w inżynierii środowiska", 2001, WNT.
- [5] Group Project, "Ventilating textile surfaces. A new approach to personalized ventilation", Indoor Environmental Engineering, 2006, Aalborg University, Denmark.
- [6] www.flomerics.com, on-line Flovent help

# 9.CHAPTER

# DISCUSION



This invention has been described in its preferred forms with a certain degree of particularity. It is noteworthy that the present disclosure of the preferred forms is only a prototype, which has been made by way of example and numerous changes in the details of construction personal ventilation diffuser and combination of different setups. After comparing the results for different cases final conclusion can be drawn.

- MV as a single system is unacceptable because ventilation index values are lower than 1.

- DV as a single system is acceptable but ventilation index reaches the lowest level.

- Combine ventilation system is more efficient rather than single system, what is clearly seen when MV is compared with MV+PV system
(comparison DV with DV+PV system is also correct).

- Top part of any diffuser provides the best results and it neither depend on type of ventilation system (MV+PV or DV+PV) nor kind of diffuser (seat cover or seat strap).

- Using middle or both parts of PV diffuser depends on type of ventilation system but it does not depend on type of diffuser.
However, for the same amount of airflow supplied to the diffuser, any case, except top part, provides less ventilation index.

- Displacement ventilation combined with personal ventilation provides much higher ventilation index than any other setup.

- The highest ventilation index (5,42) is obtained in case of displacement and personal ventilation system for 5 l/s and 15 l/s per 2 persons in one row respectively.

- It is possible to use competitive setup bases on mixing ventilation combine with personal ventilation, but still with worse result, even for extreme setup 3 l/s from MV plus 12 l/s from PV.

- Increase of airflow from personal ventilation diffuser causes increase of ventilation index, however, too high airflow causes thermal discomfort.

- Seat strap diffuser causes less draft than seat cover diffuser (comparing cases with the same airflow from PV). However, it is still possible to obtain satisfactory thermal comfort if low airflow is supplied to seat cover diffuser.

- Velocity near passenger's legs, who is sitting on the seat next to the window, is higher in case of displacement ventilation than for the same airflow in mixing ventilation system. However, velocity near passenger's legs who is sitting on the corridor seat is the same for both ventilation systems.

- CFD results confirm that CFD simulations should be mostly use in connection with other tool, rarely like a single design tool. Results for DV plus PV system show that values from measurements and their digital equivalents can be diametrically opposed to each other. However, for special case it is possible to obtain very similar results like it is for single MV and single DV.

- Repetition of measurements shows that in special cases little changes in ambient conditions can highly influence in results.

Some advices for further optimization of personal ventilation in aircraft are presented below:

- If final setup includes high airflow from PV diffuser, local thermal comfort, for different temperatures of supply air, has to be investigated in further researches. Base on equivalent homogeneous temperature (EHT) described in 'New Solution For Personalized Ventilation in Aircrafts', the thermal comfort around passenger's head should be especially taken into consideration [1]

- To lower velocity close to the passengers' legs in displacement ventilation it is suggested to change the shape and dimension of supply DV diffuser.

- Not only maximal velocity should be measured for better view on thermal comfort. It is advised to put anemometers close to passenger's legs, chest and head. Additional anemometers are substantially in the corridor to make velocity profile in cross-section.

- Experiments with another setup according to manikin's positions should be investigated. It is suggested to set Comfortina close to the curved wall with enabled breathing function, while Monkey emits tracer gas from his mouth.

- Measurements in two rows have to be done for better view how back-row passenger infects front one.

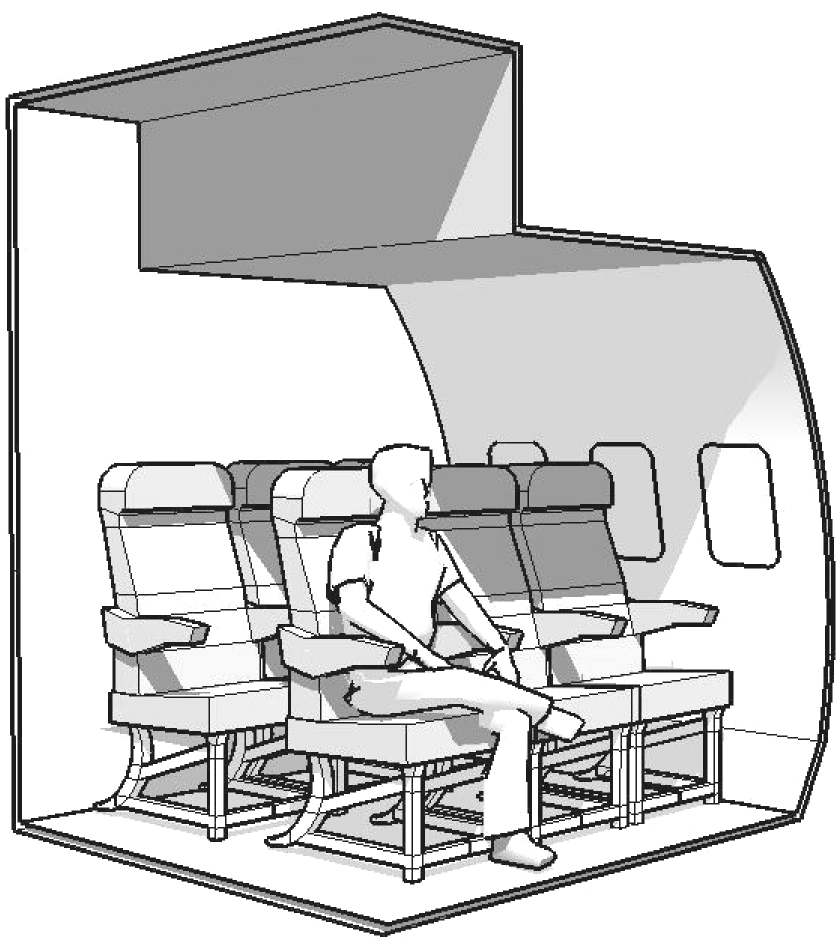
- Improvements for air quality in the corridor should be made.
  It is suggested to add directional nozzles to the edge of overhead shelf and/or exhaust system on the ceiling along corridor. For this innovation it is advised to start measurements for small airflow from exhaust ceiling system because high velocity can disturb whole airflow provided by PV and DV or MV systems.

- It is also suggested to check temperature impact on efficiency of PV diffusers as well as inclination angle of airplane seat and PV diffuser.

***Bibliography:***


- [1] E. Barszcz, T. Czarnota, D. Dymalski, M. Jasieński, A. Mozer, A. Nowotka, S. Wiankowska, “New solution for Personalized Ventilation in Aircrafts. Ventilating textile Surfaces” Aalborg University 2007,

# APPENDIX A -
# LABORATORY



## A.1. Location

Laboratory is situated in building A at Aalborg University Faculty of Civil Engineering.

The whole laboratory with size of 1143 $m^3$ is divided into two rooms. First part of our measurements (one manikin) is conducted in room called "wind tunnel" which is situated in the west part of laboratory, near the windows. Figure below shows location of rooms in the laboratory.

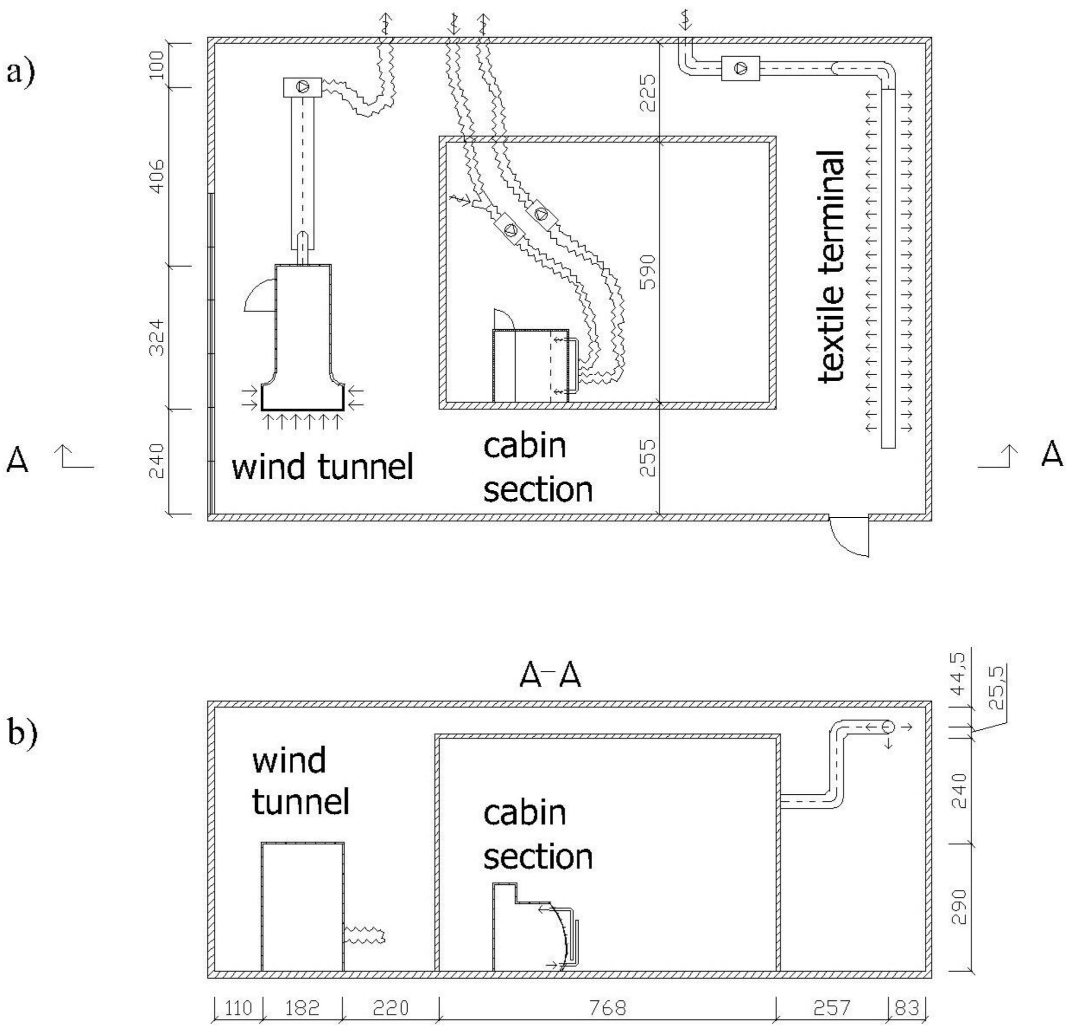



*Figure A.1. Location of models in laboratory.*

The second part of our measurements is done in a different model (cabin section), which is located inside big chamber in the middle of laboratory.

## *A.2. Inflow and outflow*

Laboratory is supplied with outside air, which is supplied to the laboratory by a textile diffuser (low velocity inlet).

Outflow air stream is generated by fan, which is connected by pipe to the wind tunnel. The fan sucks air through the south wall of wind tunnel, which is made from air permeable material, and throws it outside of the laboratory.

Flow rate volume for supply and exhaust air is equal. In the result, there is no underpressure or overpressure that could influence velocity results.

In case of cabin section model, we have inlet through the jets on top part of curved wall of model and outlet on the bottom. However, system is designed in the way that it is possible to switch inlet with outlet while considering displacement ventilation.
Fresh air is taken from outside and, according to needs, is mixed with indoor-hotter (see Figure A.2.1.) either heated by electric heater to obtain 23$^{o}$C. Exhaust goes outside of laboratory. However, to avoid returning contaminated air back to supply ducts, exhaust pipe is longer than supply. The outlet is around 6 meter away from inlet (and thanks to flexible duct can be located in different places, according to wind direction). In addition, inlet is cover with special box with holes, to protect opening from wind influence. Figure A.2.1. shows one of the possible locations.


*Figure A.2.1.. Left: Triangular part of duct for mixing outdoor (colder) air with indoor (hotter). Right: Fresh air inlet (inside the box) and exhaust outlet (flex duct).*

### A.2.1. Laboratory conditions

Thanks to weather changes outside laboratory, temperature inside changes a little.
The temperature in wind channel is held in equilibrium about 20°C. Humidity in laboratory varies between 50 and 60%.
Illumination inside the laboratory is mainly artificial illumination, permanent during all tests.

### A.2.2. Descriptions of a models

#### A.2.2.1. Wind Tunnel

Wind tunnel is a specific room where the drought is made in an artificial way. Air speed inside is generated by the fan and varies between 5 cm/s and 20 cm/s. Air flow in the wind channel goes through an air-permeable wall and finds its outlet in the exhaust pipe connected to the fan. Used air is blown outside the laboratory.

All dimensions and distances are shown in the Figure A.2.3.:

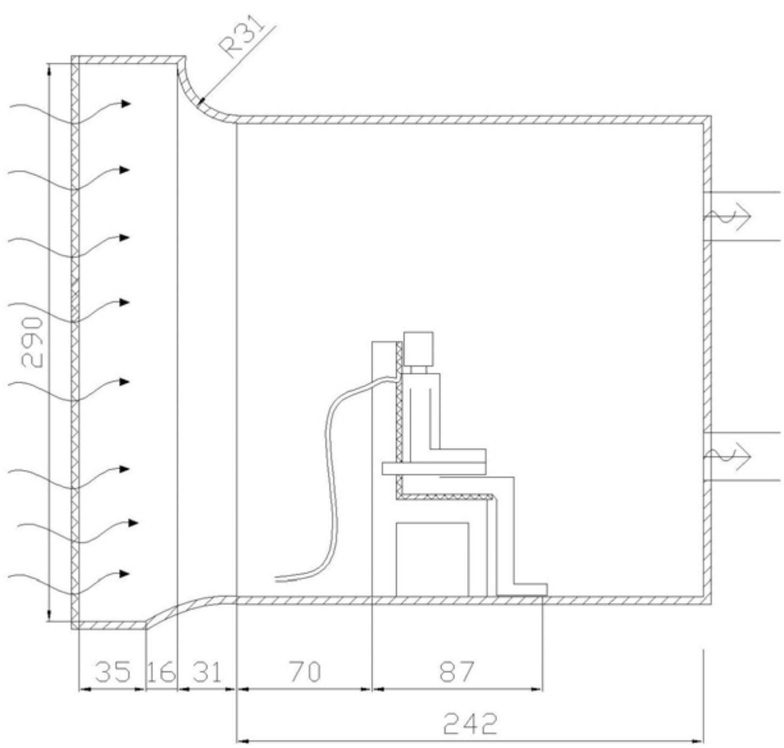



*Figure A.2.3. Wind tunnel section.*

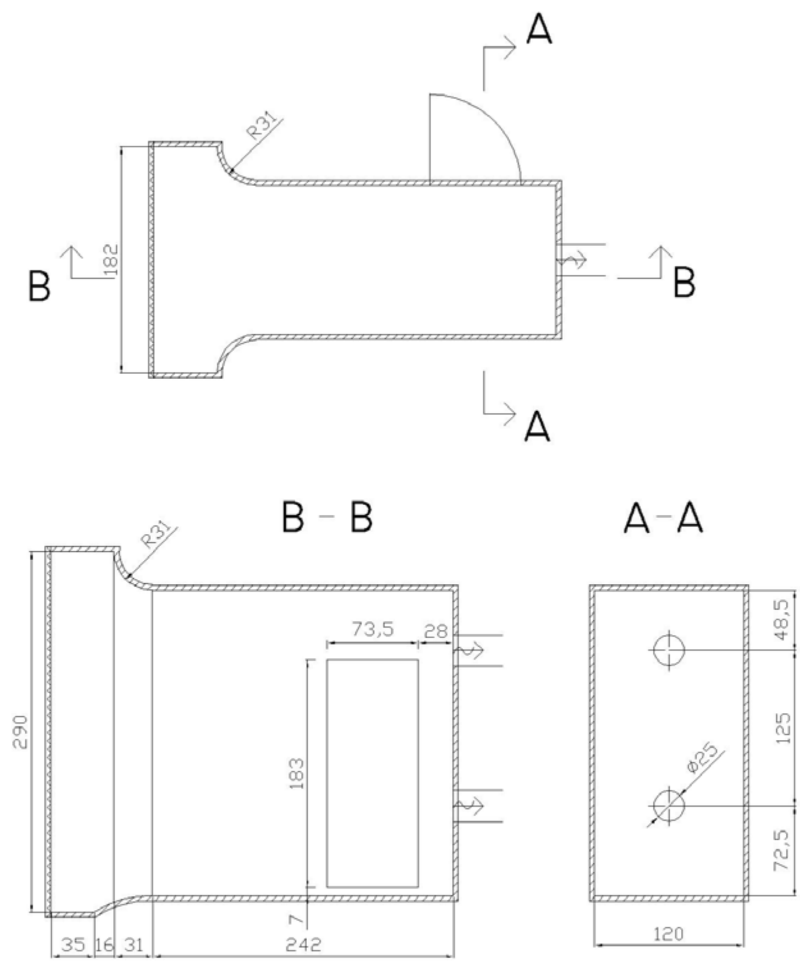



*Figure A.2.4. Wind tunnel*

### A.2.2.2. Cross Section Model

Designing this model we wanted to make it the same shape and dimension as a part of Boeing 737 -200 aircraft. We decided that model in 1:1 size would reflect conditions inside the plane.

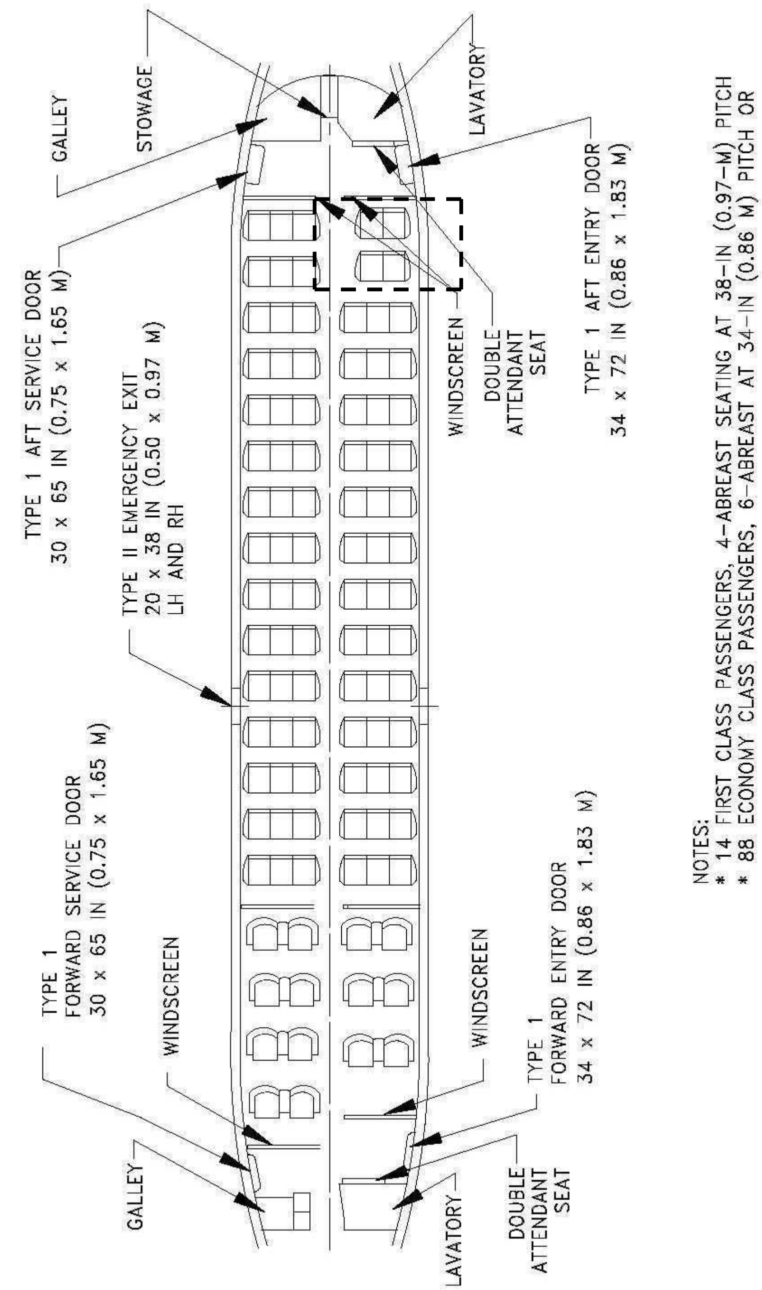



*Figure A.2.5. Interior arrangements-mixed class, model 737-200 (with marked section used in project) [1]*

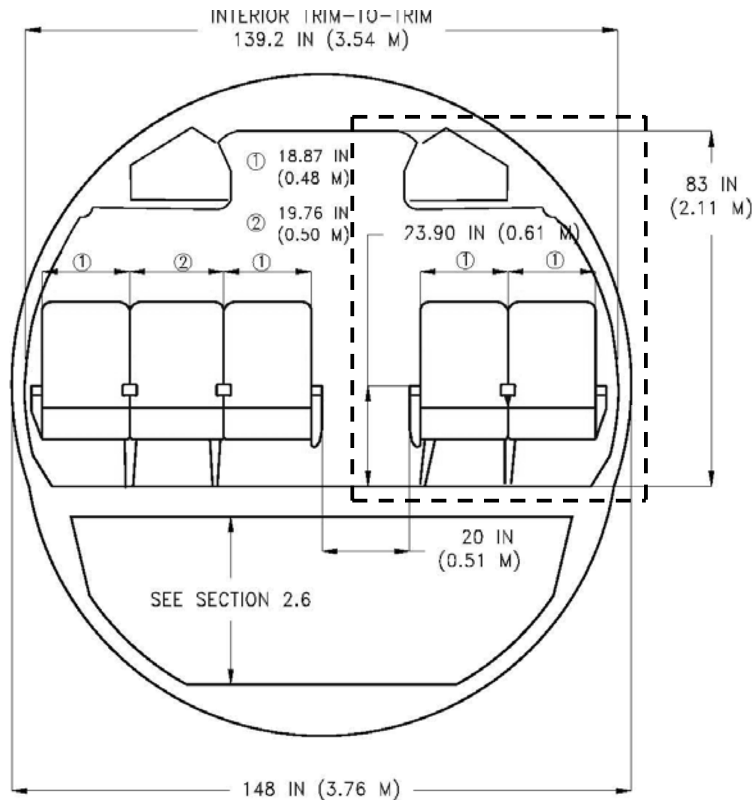



*Figure A.2.6. Cross section of model 737-200 (with marked section used in project) [1]*

Cabin section model represents section of two rows of seats on one side of corridor (due to symmetry along main corridor). Two manikins are located on a back row.

Figure A.2.7. presents dimensions of aircraft section as well as a idea of inlet and outlet.

It is possible to switch inlet with outlet (Section 'A' with Section 'B') to change mixing ventilation to displacement system.

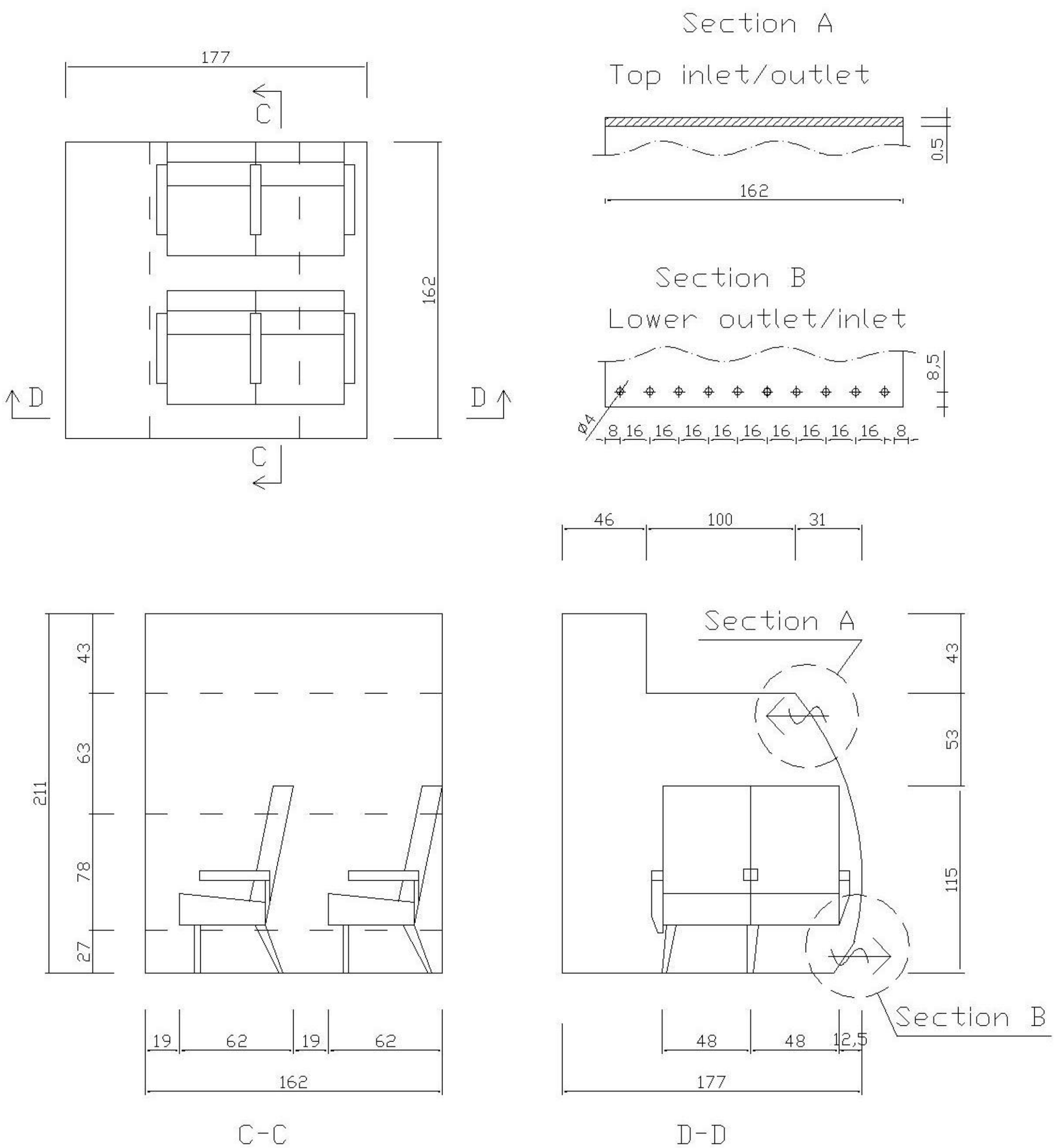


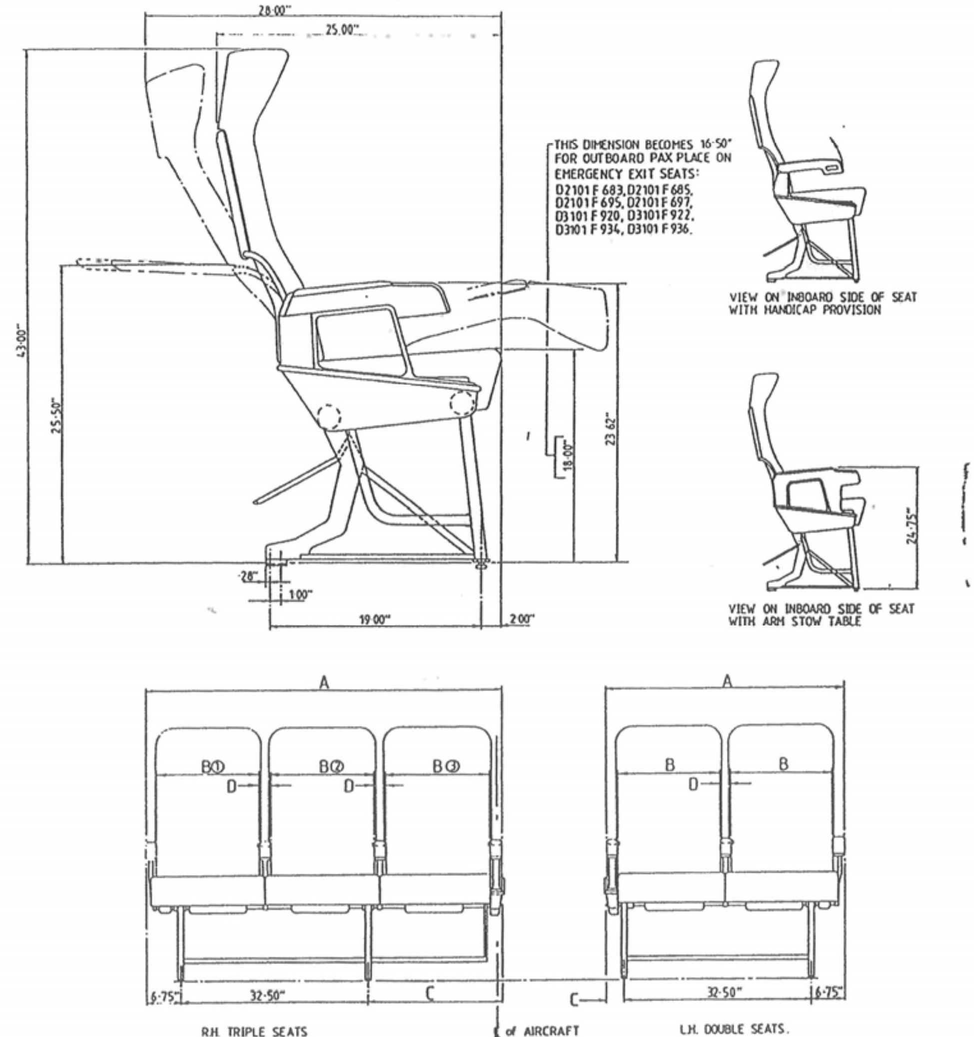

*Figure A.2.7. Cabin section model with inlet and outlet sections (A + B)*

### A.2.2.3. Aircraft seats

Seats using in project are real equipment of Boeing 737-200 craft. Two double- and one single-seat types are used during experiments. Figure A.2.8. shows scan of catalog card of seats used in SAS Airlines planes.

FLIGHT EQUIPMENT AND ENGINEERING LIMITED

OVERHAUL MANUAL




| DOUBLE SEATS | A | B | C | D |
|---|---|---|---|---|
| D2101F675 | 41.80 | 17.90 | 2.55 | 2.00 |
| D2101F677 or 681 or 683 or 685 or 715 | 41.80 | 17.40 | 2.55 | 3.00 |
| D2101F679 | 41.80 | 17.40 | 2.55 | 3.00 |
| D2101F699 or 719 or 725 | 41.80 | 17.90 | 2.55 | 2.00 |
| D2101F701 or 731 | 41.80 | 17.90 | 2.55 | 2.00 |
| D2101F687 or 688 | 41.80 | 17.90 | 2.55 | 2.00 |
| D2101F689 or 690 or 693 or 695 or 697 or 717 or 727 | 41.80 | 17.90 | 2.55 | 2.00 |
| D2101F691 | 41.80 | 17.90 | 2.55 | 2.00 |

| TRIPLE SEATS | A | B | C | D |
|---|---|---|---|---|
| D3101F912 | 61.70 | 17.90 | 22.45 | 2.00 |
| D3101F914 or 916 or 918 or 920 or 922 | 61.70 | ① 17.15 ② 17.40 ③ 17.15 | 22.45 | 3.00 |
| D3101F924 or 942 | 61.70 | 17.90 | 22.45 | 2.00 |
| D3101F926 or 960 | 58.76 | 16.92 | 19.51 | 2.00 |
| D3101F928 or 932 or 934 or 936 | 61.70 | 17.90 | 22.45 | 2.00 |
| D3101F930 | 61.70 | 17.90 | 22.45 | 2.00 |
| D3101F938 or 940 | 58.76 | 16.92 | 19.51 | 2.00 |

ALL DIMENSIONS ARE IN INCHES

SAS SEAT DIMENSION DIAGRAM – MD 81, MD 82 & MD 87 AIRCRAFT Fig. B

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PAGE 4
AUGUST 1991

*Figure A.2.8. Seat dimension diagram (SAS Scandinavian Airlines)[2]*

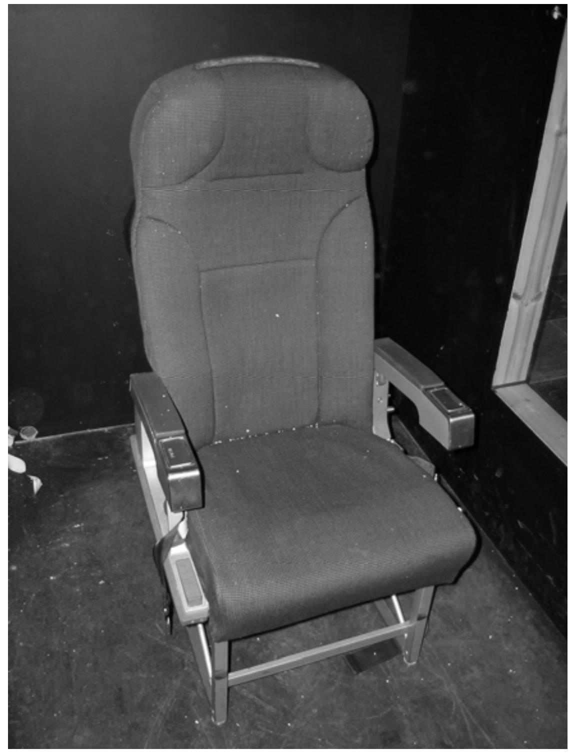
 

*Figure A.2.9. Double seats from cabin section model (left) and single seat from wind tunnel (right).*

## A.3. Laboratory equipment

To measure temperature, velocity, gas concentration and thermal comfort the laboratory is composed of fallowing equipment:

1) Micromanometer
2) Fan
3) Tracer gas supply
4) Gas transfer pipes
5) The Multipoint Sampler, Doser and Monitor
6) Thermocouples
7) Grant SQ1600 Squirrel Meter/Logger
8) The thermal anemometer
9) The Low Velocity Flow Analyzer

Scheme of equipment set up for wind tunnel and cabin section is shown in a Figure A.3.1. and Figure A.3.2.

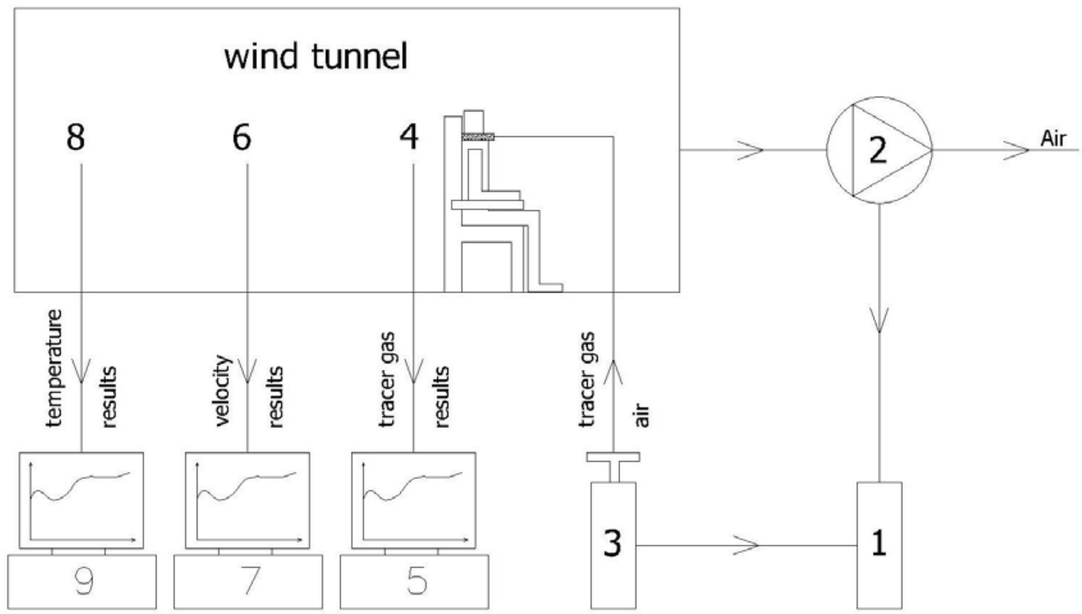



*Figure A.3.1. Scheme of laboratory equipment used in wind tunnel*

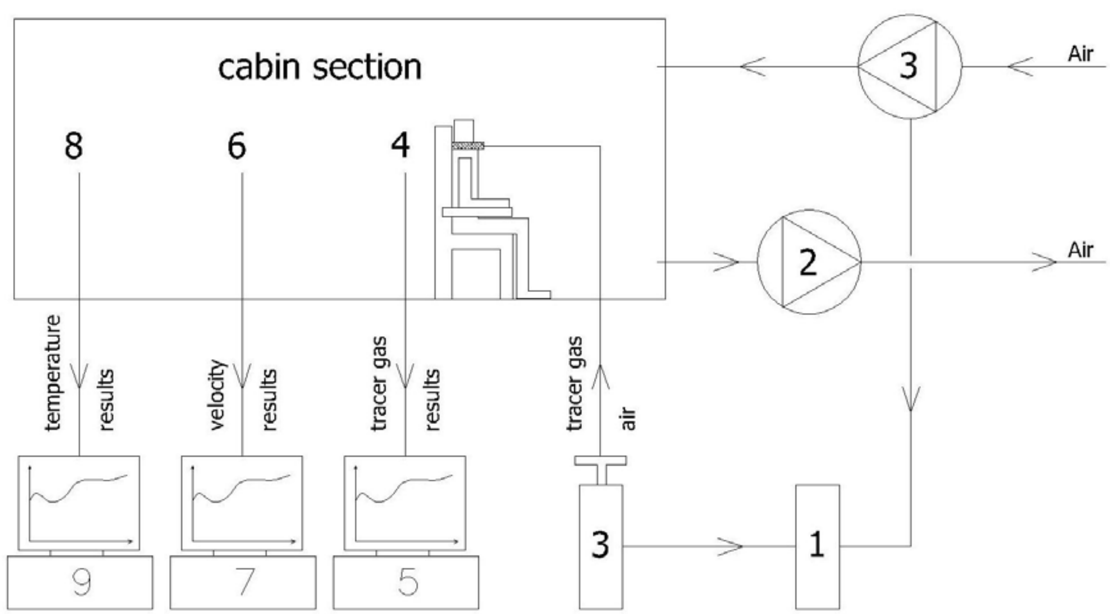
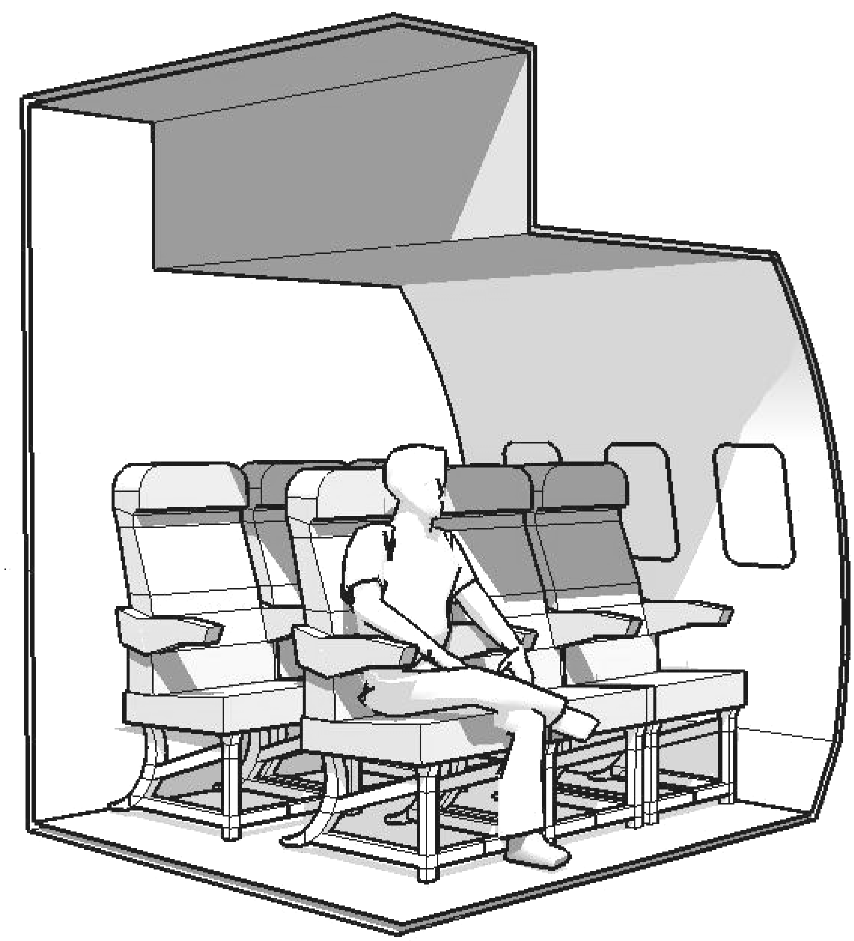



*Figure A.3.2. Scheme of laboratory equipment used in cabin section*

***Bibliography:***


- [1] Boeing 737 (all version) airplane description - D6-58325-6
- [2] SAS Scandinavian Airlines documentation

# APPENDIX B -
# EQUIPMENT



## *B.1. Temperature*

### B.1.1. Equipment

Thermocouples are the most widely used temperature sensor in tests and development works. They consist of two dissimilar metals, which produce an electromotive force roughly proportional to the temperature difference between their measuring junction (the hot junction that is used to measure an unknown temperature) and reference junction (a cold junction at a known temperature). According to different needs (industrial, scientific, food temperature, etc.) there are many different types of sensors. All of themes differ with used materials, the reference and the junction temperature. [1]

The three most common thermocouples alloys for moderate temperatures are Iron-Constantan (Type J), Copper-Constantan (Type T), and Chrome-Albumen (Type K).

During our measurements thermocouples type K are used. Thermocouple type K is very popular due to a wide range of practical usage and low price. Its working parameters vary from −200°C to +1200°C. To vary the thermocouple wiring colors are used (the type K is green).

An example wire is shown in Figure B.1.1.

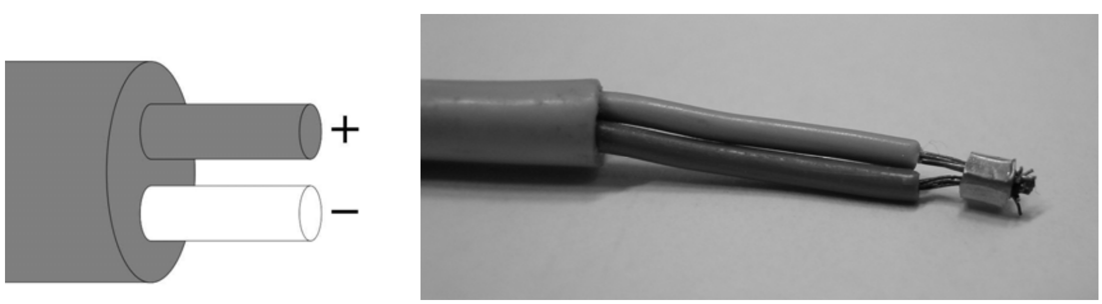



*Figure B.1.1. K-type thermocouple*

Thermocouples were gathered by the Grant Squirrel SQ1600 device (see Figure X). Grant transfers all data to PC, where Grant Data Logging (Squirrel Logger) analyses results and exports them to excel files.

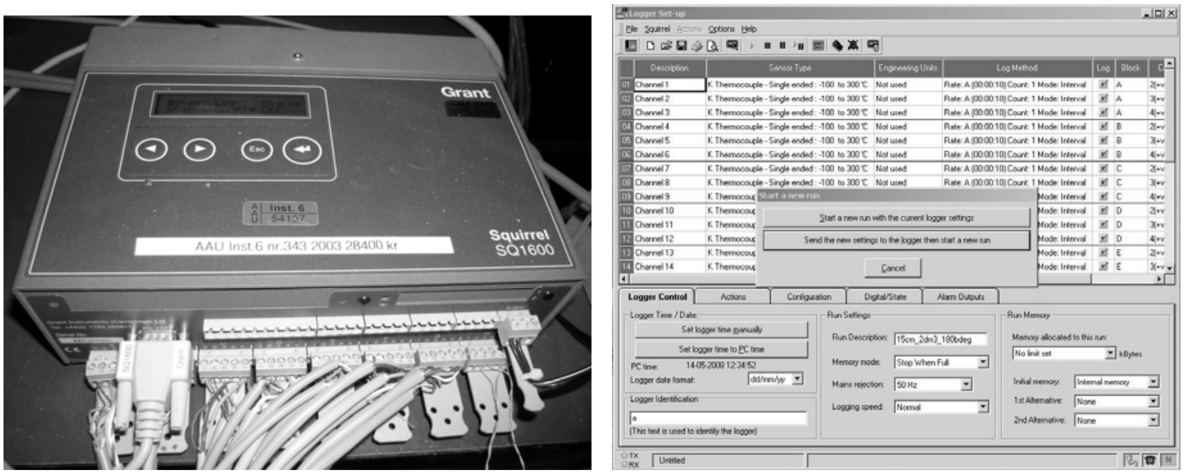



*Figure B.1.2.. Left: Grant Squirrel SQ1600, right: Grant Data Logging (Squirrel Logger).*

### B.1.2. Calibration

The temperature calibration of the thermocouples was done during last semester project [6]. Calibration values as well as the curves can be found in its report or attached CD.

## *B.2. Velocity*

### B.2.1. Equipment

In our project we are using hot sphere anemometers (DANTEC 54R10). This Equipment let us measure velocity inside the wind tunnel. Figure B.2.1. presents how the anemometers with their protecting covers look like.

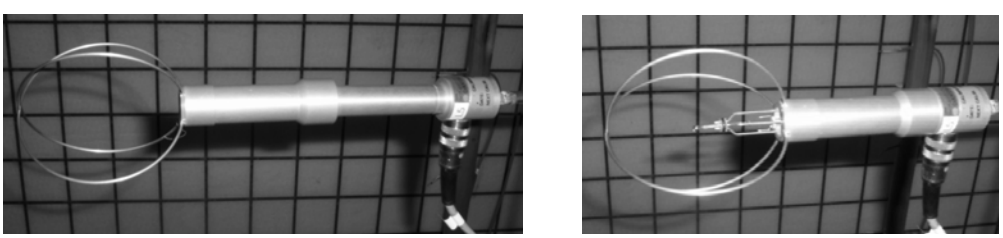


*Figure B.2.1. DANTEC 54R10 anemometers. Left: closed, right: opened (visible sphere).*

The anemometers measure velocity according to the amount of the heat taken away from the fluid.  There is hot sphere inside the core of anemometer. The heat loss to fluid flow is a function of the fluid velocity. Measuring temperature changes on sphere surface it is possible to calculate heat lost, which is automatically converted into a fluid speed. [2]

Anemometers are connected to low velocity analyzer, which transfers data to PC program Dantec Dynamics.

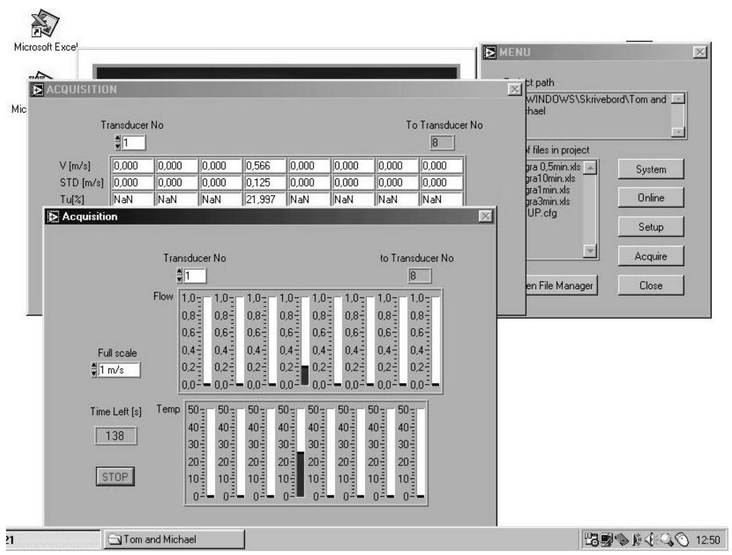


*Figure B.2.2. Dantec Dynamics*

### B.2.2. Calibration

The anemometers calibration was done for last semester project [6]. Calibration values as well as the curves can be found in last semester report or attached CD.

## *B.3. Tracer Gas Concentration*

To measure concentration of tracer gas – dinitrogen oxide (N2O) we are using Multipoint sampler as well as dozer equipment (type 1303).

These two tools are connected to monitor type 1302 (Bruel & Kjaer Multigas). Everything is controlled by software for Tracer-gas Monitoring Systems, type 7620. During measurements graphic results are displayed on PC's screen, and transferred into excel files.

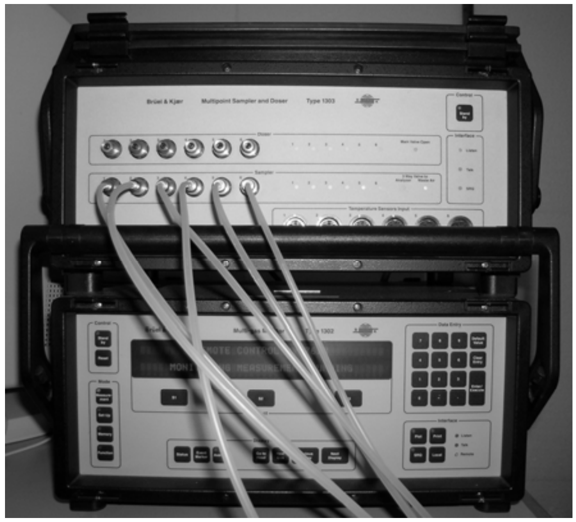


*Figure B.3.1. The tracer gas measuring device.*

The idea of measuring of concentrations is that the sampler system takes a sample of the air from the room and delivers it to the Multigas monitor type 1302 for analysis. The only one limitation is that max. 6 samples can be measured in the monitor, one by one. Multigas transfer data to PC program called Innova AirTech Instruments-Type 7620 (see Figure B.3.2.). [6]

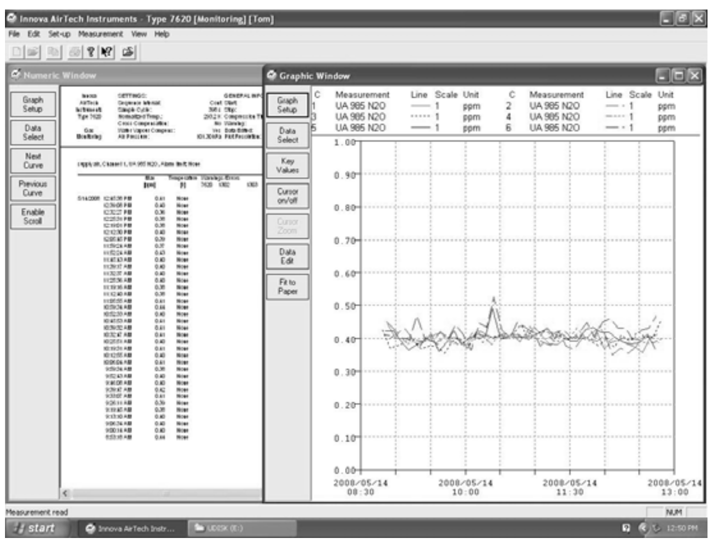



*Figure B.3.2. Innova AirTech Instruments-Type 7620*

To adjust exact amount of $N_2O$ delivered to system, we are using macro valve, adjusted to 1 bar, and micro valve to 3l/s. (see Figure below)

*Figure B.3.3. Bottle with tracer gas, micro and macro valves.*

.

## *B.4. Artificial Lungs*

This equipment is responsible for breathing function manikins being used during measurements. It is necessary to connect manikins with lungs using special tubes to enable respiration process. It is possible to adjust appropriate amount of inhaled and exhaled air as well as frequency of respiration (in the range of 3-30 breaths per minute) and the pulmonary ventilation (5-18 liter per minute).
Artificial Lungs have also the possibility to set respiration either through the mouth or/and nose.


*Figure B.4. Artificial lungs.*

## *B.5. Manikins*

During our experiments we are using two thermal manikins with breathing functions. One is modern, simulating women- “Comfortina”, other one is simplified model- “Monkey”.

### B.5.1. Comfortina

This Breathing Thermal Manikin (BTM) “Comfortina” is used in both, wind tunnel cabin section model, experiments.

BTM is model of an average size woman. Its height is 1,7m and size 38. Her body is divided into 17 separately heated sectors, to reflect natural temperature of human’s body. To enable manikin stand or sit, it is equip with shoulder, hip and knee joints. Figure B.5.1. shows all the segments division and Table B.5.1. surfaces areas. [3]

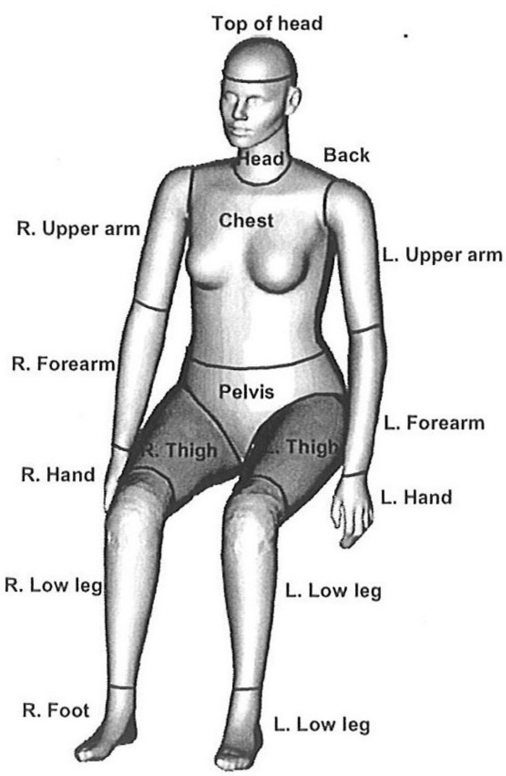



*Figure B.5.1. Comfortina with segments division, originally from the Technical University of Denmark.*

| No. | Body segments | Area ($m^2$) |
|---|---|---|
| 1 | left foot | 0,043 |
| 2 | right foot | 0,043 |
| 3 | left low leg | 0,09 |
| 4 | Right low leg | 0,16 |
| 5 | Left thigh | 0,16 |
| 6 | right thigh | 0,17 |
| 7 | pelvis | 0,076 |
| 8 | head | 0,038 |
| 9 | Left hand | 0,037 |
| 10 | right hand | 0,05 |
| 11 | left forearm | 0,05 |
| 12 | right forearm | 0,0773 |
| 13 | left shoulder | 0,0773 |
| 14 | right shoulder | 0,14 |
| 15 | chest | 0,13 |
| 16 | back | 0,05 |
| 17 | top of head | 0,05 |

*Table B.5.1. Surface area for the body segments of the BTM Comfortina. [3]*

Heating Comfortina is possible due to 4mm fiberglass-armed polyester shell that is rolled with a nickel wire 1mm thick protection shield. [5]

Thanks to manikins breathing function an keeping specified surface temperature it is possible to measure the PV effectiveness and its influence on thermal comfort. The skin temperature is measured in the range of 18°C – 37°C with the accuracy of 0.1°C and a maximum heat loss of 140 W/m$^2$.

During the experiment the manikin was wearing ordinary tight-fitting clothes with an insulation value 0.8 clo. It is an average value (typical clothing insulation varies between 0,5 clo and 1,0 clo).

*Figure B.5.2. BTM Comfortina.*

To control manikin two computer programs are used: CONTROL and MANIKIN. MANIKIN is a program that presents the various temperatures and transmits the measurements to the file or a printer. CONTROL is a memory-resident driver for constant measurement of the surface temperature. Necessary power is transferred to each part of the manikin to obtain accurate body temperature. [4]

MANIKIN program let user control the surface temperature and heat loss in a listed figure. Also picture with different temperature ranges marked with colours is also available for better control. In addition, there is possibility to check on a graph the last 1-hour variation in mean surface temperature. All data are collected under steady-state conditions.

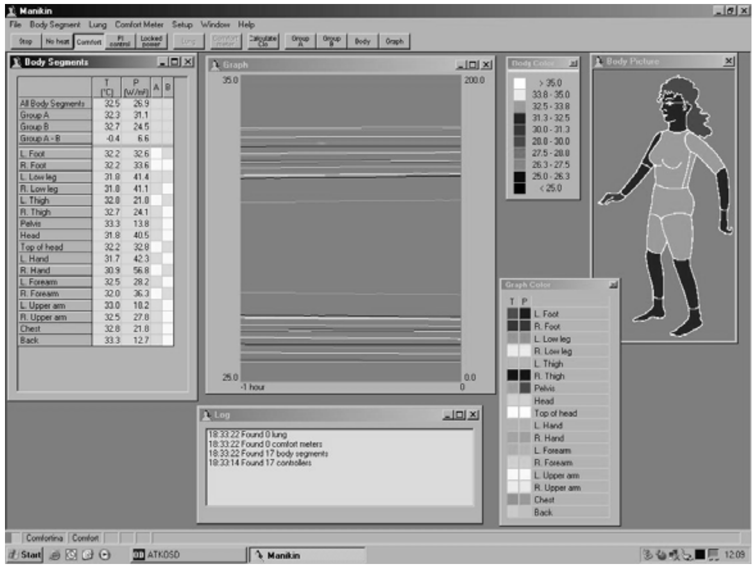


*Figure B.5.3. MANIKIN program with surfaces temperature presentation.*

In order to check the effectiveness of PV, Comfortina can be connected to artificial lungs that are stimulating breathing functions. The nostrils and the mouth are circular openings 12 mm in diameter.

### B.5.2. Monkey

This is 170cm-height simplified model of human being constructed at Aalborg University. Manikin represents the physical functions such as respiration and heat emission. It has an internal heating system that corresponds to the human's heat load. It is possible to adjust certain heat load by using the heat controller (see Figure B.5.5.). Using Monkey, it is possible to measure air quality, but it not possible to control thermal comfort (while Comfortina can both).

Monkey is used only in cabin section model experiments.

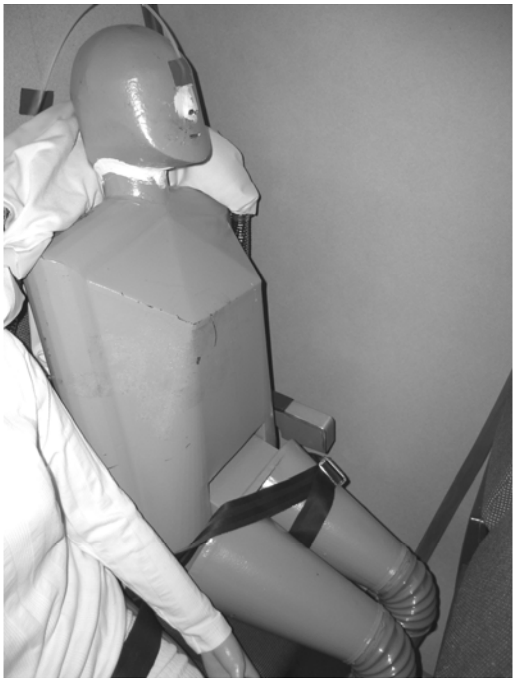


*Figure B.5.4. Left: Monkey manikin. Right: heat controller*

## *B.6. Fans and control system*

During our measurements we are using different types of fans (according to model we are working on) with different regulators.

Pressure drop on a orifice plate are checked by using the micromanometer Debro Meerbush Germany. Rubber pipes connect device with orifices.

*Figure B.6.1. Micromanometer.*

### B.6.1. Exhaust fan in wind tunnel model

This fan was located in the middle of exhaust duct from wind tunnel. EXHAUSTO A/S fan Type BESB 50043 was run by Grundfos Engine (see Figure B.6.2.).

*Figure B.6.2. Left: exhaust fan; right: fan regulator*

### B.6.2. Supply and exhaust fan in cabin section model

Two twin fan made by LINDAB type CBUK 100B are used both to supply and exhaust duct. Devices are connected with model with flex pipes. Figure CCC shows fans with their regulators. To supply Danmarks Ingeniorakademi Elekronisk Lab type 2422 530 05404 fan is used, and to exhaust Regavolt Variable Transformer type 708 Lab.
Air flow rate in exhaust is determined by the pressure drop on the Fläkt type EHBA-800-1 orifice plate (2-5 m/s). Air flow rate in supply air is checked by comparison of pressure inside and outside cabin section (eliminating over/under pressure).

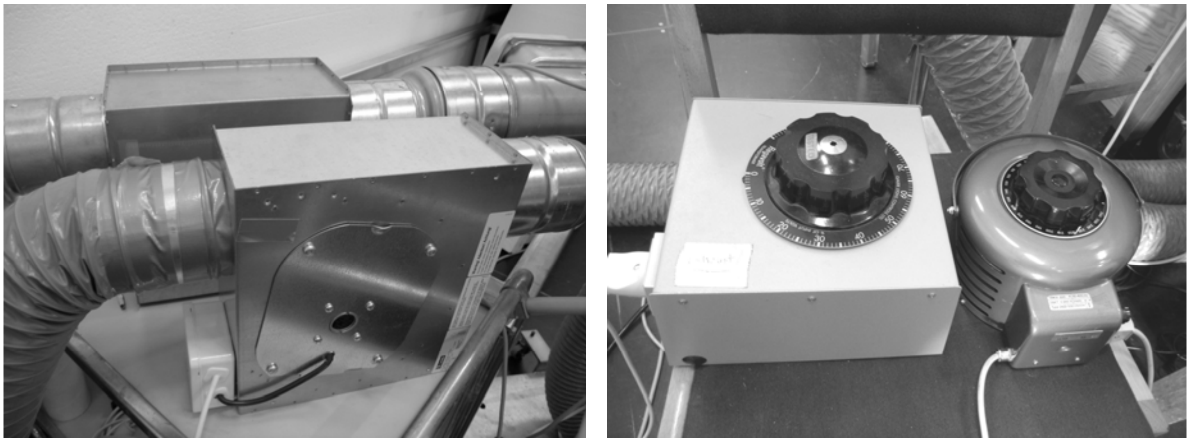


*Figure B.6.3. Left: two identical fans (front-exhaust, back-supply), right: regulators (left-exhaust, right supply).*

### B.6.3. Personal Ventilation fan in both models

Diffusers are supplied with air from an EBM 62D180-AE02-01 fan. The fan motor is operated using a Variable Speed Drive VLT (Danfoss). According to the air flow rate two different orifice plate are used (see Figure B.6.4.). For air flows 16-8 l/s – 34mm and for 6-2 l/s – 22mm.

To connect fan with PV diffusers flexible ducts are used.

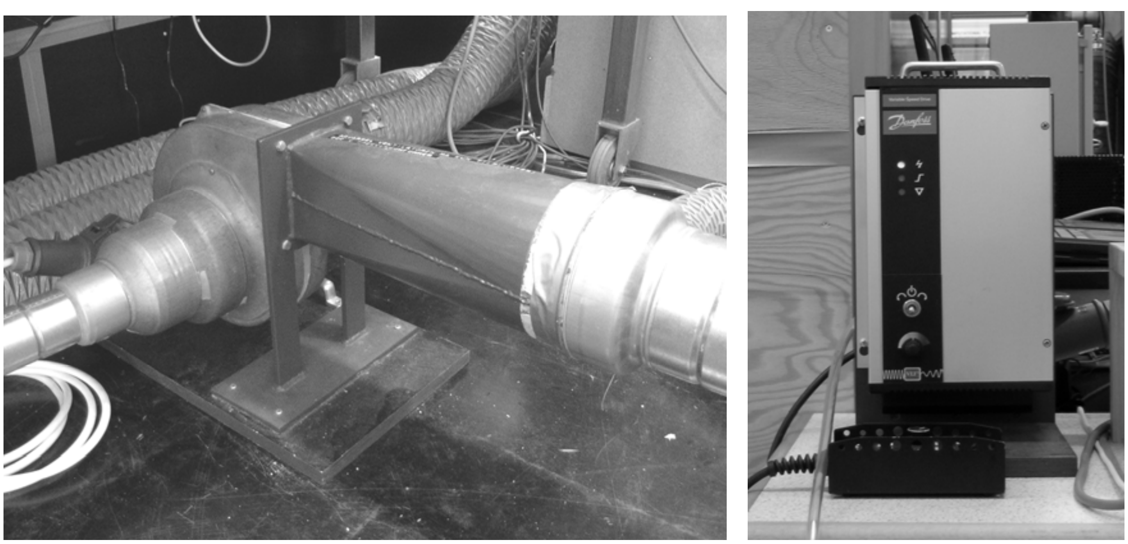


*Figure B.6.4. Supply fan (left) with regulator (right).*

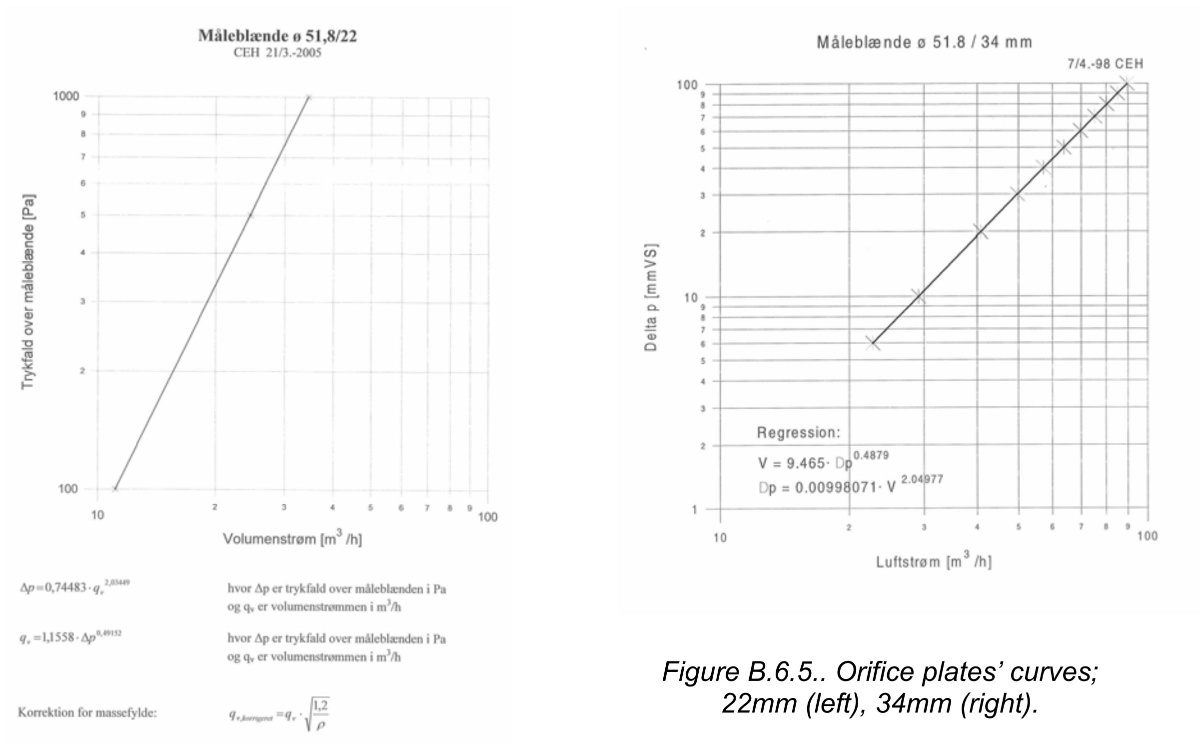



*Figure B.6.5.. Orifice plates' curves; 22mm (left), 34mm (right).*

## *B.7. Smoke equipment*

To obtain better results and to visualize work of personal ventilation we smoke simulations are used. Smoke gives better understanding how fresh air is distributed in model and between aircraft passengers.

In order to conduct smoke simulation special oil-based smoke machine is connected to the ducts (see Figure B.7.). This device changes state of special liquid oil, under the influence of temperature, from matter into gaseous form.
According to temperature (regulated using remote controller), smoke machine is producing required amount of smoke delivered to the ducts.

Smoke is non-toxic and safe to use.

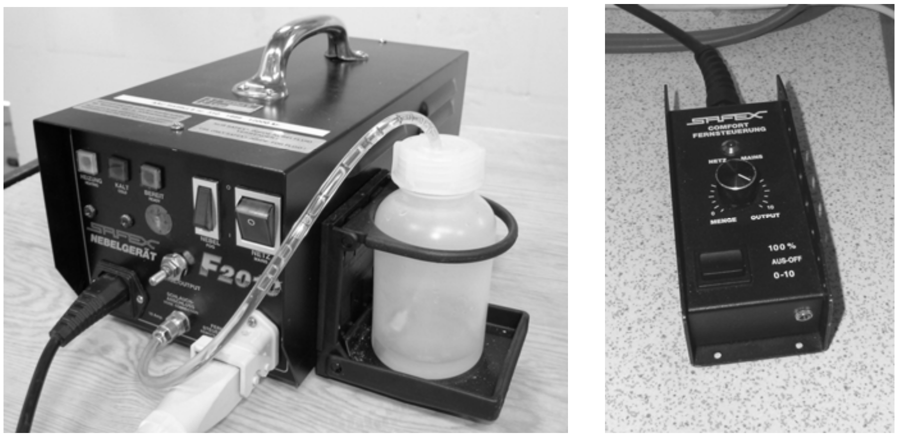
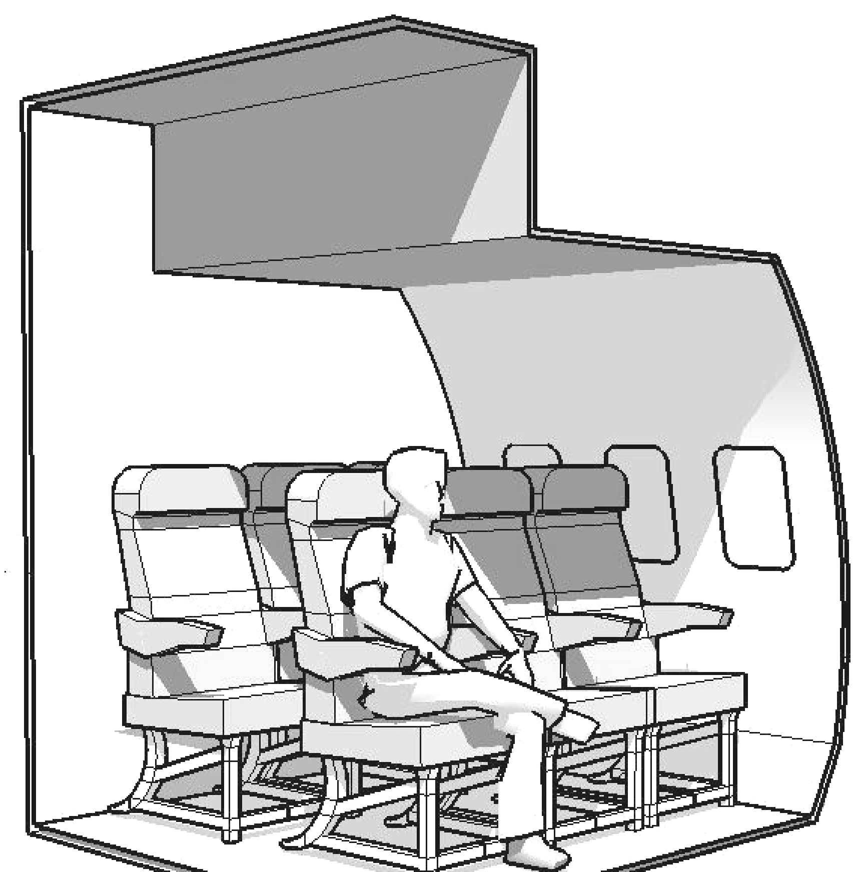



*Figure B.7. Oil-based smoke machine (left) and remote controller (right)*

### *Bibliography:*


- [1] Ewa Jakubowska, Sara Thomas, Adam Mierzejewski, Marcin Polak. „Ventilating Textile Surfaces, A new approach to personalized ventilation"; 9th semester project; Aalborg University 2007
- [2] Hao Jiang, Karolina Krawiecka, Kasia Trąmpczyński, Niels Moller Bartholomaussen, Oli Josson. "The Design of Personalized Ventilation in Airplanes and Hospitals"; 9th semester project; Aalborg University 2007
- [3] Thomas Lund Madsen, "Description of a new second generation thermal manikin"; .Thermal Insulation Laboratory, Technical University of Denmark
- [4] Claus Bidstrup, "MANIKIN version 3.0"; Department of Buildings and Energy, Technical University of Denmark (September 1996).
- [5] Peter V. Nielsen and another, "Chair with Integrated Personalized Ventilation for Minimizing Cross Infection"; Roomvent, Helsinki 2007
- [6] E. Barszcz, T. Czarnota, D. Dymalski, M. Jasieński, A. Mozer, A. Nowotka, S. Wiankowska, "New solution for Personal Ventilation in Aircrafts. Ventilating textile Surfaces" Aalborg University 2007,

# APPENDIX C -
# DETAILED CONCENTRATION RESULTS



# *C.1. Concentration results for measurements in the wind tunnel*

## C.1.1. Seat strap, top part, velocity 0,12 m/s in wind tunnel. Seat position 180 °

| *Concentration results for seat cover top part for velocity 0,12 m/s in the wind tunnel* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Supply airflow* | *Measurement No.* | *Monkey's nose $C_{exp,PV}$* | *Near permeable wall* | *Supply PV diffuser $C_{PV}$* | *On the anemometer* | *Laboratory $C_{lab}$* | *Leakage from the gas bottle* | *Effectiveness $\varepsilon_{PV}$* |
| [l/s] | [-] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [-] |
| 15 | 1 | 72,01 | 1,41 | 77,36 | 31,98 | 1,42 | 1,54 | 92,95 |
| | 2 | 67,88 | 1,61 | 78,29 | 4,85 | 1,45 | 1,75 | 86,45 |
| | 3 | 69,64 | 1,65 | 76,52 | 41,45 | 1,63 | 1,93 | 90,81 |
| | 4 | 76,16 | 1,78 | 76,85 | 9,29 | 1,61 | 1,94 | 99,08 |
| | 5 | 71,73 | 1,88 | 75,65 | 28,76 | 1,70 | 2,17 | 94,70 |
| | Mean value | 71,48 | 1,67 | 76,93 | 23,27 | 1,56 | 1,87 | **92,80** |
| 14 | 1 | 80,70 | 2,04 | 83,72 | 46,12 | 1,85 | 2,35 | 96,31 |
| | 2 | 86,82 | 1,94 | 86,34 | 28,70 | 1,81 | 2,23 | 100,57 |
| | 3 | 79,95 | 2,19 | 85,53 | 24,12 | 1,83 | 2,41 | 93,33 |
| | 4 | 85,59 | 2,15 | 89,99 | 25,49 | 1,81 | 3,72 | 95,01 |
| | 5 | 78,59 | 2,08 | 80,97 | 23,99 | 1,78 | 2,36 | 96,99 |
| | Mean value | 82,33 | 2,08 | 85,31 | 29,68 | 1,82 | 2,61 | **96,44** |
| 12 | 1 | 93,80 | 2,17 | 95,40 | 56,72 | 1,96 | 2,06 | 98,29 |
| | 2 | 91,14 | 2,13 | 101,90 | 43,46 | 1,93 | 2,08 | 89,24 |
| | 3 | 87,75 | 2,10 | 97,27 | 39,84 | 1,92 | 2,62 | 90,02 |
| | 4 | 97,18 | 2,11 | 88,01 | 30,98 | 1,95 | 1,99 | 110,66 |
| | 5 | 91,04 | 2,19 | 104,67 | 7,68 | 1,88 | 2,52 | 86,74 |
| | Mean value | 92,18 | 2,14 | 97,45 | 35,74 | 1,93 | 2,25 | **94,99** |
| 10 | 1 | 110,13 | 2,15 | 119,94 | 22,45 | 1,87 | 2,92 | 91,69 |
| | 2 | 106,75 | 2,17 | 117,46 | 24,52 | 1,94 | 2,40 | 90,73 |
| | 3 | 107,36 | 2,23 | 119,89 | 41,48 | 1,96 | 5,17 | 89,38 |
| | 4 | 114,32 | 2,19 | 107,61 | 18,24 | 1,88 | 2,02 | 106,35 |
| | 5 | 112,20 | 2,27 | 117,96 | 29,24 | 1,96 | 2,23 | 95,03 |
| | Mean value | 110,15 | 2,20 | 116,57 | 27,19 | 1,92 | 2,95 | **94,64** |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 8 | 1 | 143,42 | 2,43 | 149,52 | 43,64 | 1,98 | 2,42 | 95,87 |
| | 2 | 115,11 | 2,27 | 134,62 | 30,02 | 2,01 | 2,43 | 85,29 |
| | 3 | 132,43 | 2,37 | 127,70 | 35,00 | 1,98 | 2,02 | 103,76 |
| | 4 | 137,22 | 2,31 | 136,62 | 48,99 | 2,10 | 2,35 | 100,45 |
| | 5 | 137,05 | 2,32 | 154,65 | 21,69 | 2,01 | 2,01 | 88,47 |
| | Mean value | 133,05 | 2,34 | 140,62 | 35,87 | 2,02 | 2,25 | **94,77** |
| 6 | 1 | 145,77 | 2,35 | 192,36 | 8,59 | 1,93 | 2,49 | 75,53 |
| | 2 | 174,47 | 2,43 | 179,66 | 8,53 | 1,95 | 2,77 | 97,08 |
| | 3 | 159,74 | 2,41 | 186,44 | 12,97 | 1,94 | 3,67 | 85,53 |
| | 4 | 164,21 | 2,39 | 205,29 | 8,36 | 1,94 | 2,65 | 79,80 |
| | 5 | 163,01 | 2,44 | 180,78 | 42,33 | 2,02 | 2,35 | 90,06 |
| | Mean value | 161,44 | 2,40 | 188,91 | 16,16 | 1,96 | 2,79 | **85,60** |
| 4 | 1 | 113,68 | 2,24 | 263,68 | 10,77 | 1,95 | 2,13 | 42,69 |
| | 2 | 175,27 | 2,42 | 267,60 | 29,53 | 2,04 | 3,17 | 65,23 |
| | 3 | 176,79 | 2,43 | 289,44 | 12,27 | 1,97 | 3,17 | 60,81 |
| | 4 | 83,99 | 2,12 | 279,06 | 15,28 | 1,99 | 3,17 | 29,60 |
| | 5 | 131,92 | 2,29 | 255,42 | 30,46 | 2,04 | 2,68 | 51,26 |
| | Mean value | 136,33 | 2,30 | 271,04 | 19,66 | 2,00 | 2,86 | **49,92** |
| 2 | 1 | 64,88 | 2,11 | 533,45 | 4,55 | 2,06 | 2,70 | 11,82 |
| | 2 | 32,99 | 1,98 | 548,40 | 16,91 | 2,06 | 2,53 | 5,66 |
| | 3 | 104,36 | 2,19 | 528,93 | 16,98 | 2,13 | 2,95 | 19,41 |
| | 4 | 37,58 | 2,03 | 513,60 | 18,65 | 2,12 | 4,40 | 6,93 |
| | 5 | 7,98 | 1,88 | 547,31 | 48,50 | 2,11 | 2,21 | 1,08 |
| | Mean value | 49,56 | 2,04 | 534,34 | 21,12 | 2,10 | 2,96 | **8,98** |

*Table C.1.1. Concentration results for velocity 0,12 m/s in the wind tunnel*

### C.1.2. Seat cover, top part, velocity 0,12 m/s in wind tunnel. Seat position 180 °

| *Concentration results for seat cover top part for velocity 0,12 m/s in the wind tunnel* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Supply airflow* | *Measurement No.* | *Monkey's nose $C_{exp,PV}$* | *Near permeable wall* | *Supply PV diffuser $C_{PV}$* | *On the anemometer* | *Laboratory $C_{lab}$* | *Leakage from the gas bottle* | *Effectiveness $\varepsilon_{PV}$* |
| [l/s] | [-] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [-] |
| 15 | 1 | 46,57 | 1,40 | 99,17 | 33,13 | 1,57 | 1,23 | 46,11 |
| | 2 | 48,29 | 1,51 | 97,61 | 30,83 | 1,81 | 1,25 | 48,52 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 3 | 28,96 | 1,62 | 98,23 | 31,64 | 1,90 | 1,58 | 28,09 |
| | 4 | 40,32 | 1,82 | 100,36 | 30,59 | 1,92 | 1,77 | 39,01 |
| | 5 | 45,48 | 1,90 | 96,32 | 18,40 | 1,83 | 2,31 | 46,20 |
| | Mean value | 41,92 | 1,65 | 98,34 | 28,92 | 1,81 | 1,63 | **41,58** |
| 14 | 1 | 32,97 | 1,96 | 96,51 | 30,00 | 1,92 | 1,90 | 32,83 |
| | 2 | 32,57 | 1,96 | 98,87 | 13,21 | 1,91 | 1,78 | 31,62 |
| | 3 | 36,25 | 2,11 | 99,71 | 33,95 | 2,17 | 1,87 | 34,94 |
| | 4 | 49,50 | 2,12 | 102,64 | 2,97 | 2,15 | 1,97 | 47,12 |
| | 5 | 38,41 | 2,06 | 102,60 | 26,24 | 2,05 | 1,91 | 36,16 |
| | Mean value | 37,94 | 2,04 | 100,07 | 21,27 | 2,04 | 1,89 | **36,53** |
| 12 | 1 | 52,14 | 2,27 | 111,28 | 36,02 | 2,11 | 1,75 | 45,83 |
| | 2 | 61,54 | 2,10 | 114,34 | 15,61 | 2,03 | 2,11 | 52,99 |
| | 3 | 32,87 | 2,14 | 116,78 | 28,41 | 2,15 | 2,00 | 26,80 |
| | 4 | 39,48 | 2,16 | 114,99 | 52,16 | 2,25 | 1,97 | 33,02 |
| | 5 | 49,19 | 2,16 | 111,56 | 25,00 | 1,94 | 1,71 | 43,10 |
| | Mean value | 47,04 | 2,17 | 113,79 | 31,44 | 2,10 | 1,91 | **40,35** |
| 10 | 1 | 53,30 | 2,30 | 122,85 | 56,84 | 2,29 | 1,99 | 42,31 |
| | 2 | 71,01 | 2,32 | 139,16 | 19,76 | 2,13 | 2,13 | 50,27 |
| | 3 | 105,09 | 2,26 | 135,29 | 32,15 | 2,12 | 2,00 | 77,32 |
| | 4 | 94,73 | 2,38 | 129,45 | 42,27 | 2,29 | 2,04 | 72,70 |
| | 5 | 83,17 | 2,35 | 130,62 | 56,57 | 2,35 | 2,08 | 63,01 |
| | Mean value | 81,46 | 2,32 | 131,47 | 41,52 | 2,24 | 2,05 | **61,12** |
| 8 | 1 | 51,39 | 2,30 | 165,09 | 63,41 | 2,34 | 2,02 | 30,14 |
| | 2 | 119,44 | 2,47 | 168,74 | 52,78 | 2,32 | 1,96 | 70,38 |
| | 3 | 110,06 | 2,34 | 162,65 | 39,89 | 2,14 | 2,07 | 67,24 |
| | 4 | 104,03 | 2,28 | 157,52 | 37,54 | 2,24 | 2,31 | 65,55 |
| | 5 | 117,93 | 2,45 | 159,53 | 54,70 | 2,33 | 2,18 | 73,54 |
| | Mean value | 100,57 | 2,37 | 162,71 | 49,66 | 2,27 | 2,11 | **61,37** |
| 6 | 1 | 131,21 | 2,36 | 205,86 | 19,84 | 2,05 | 1,84 | 63,37 |
| | 2 | 116,78 | 2,36 | 209,02 | 28,89 | 2,18 | 1,92 | 55,41 |
| | 3 | 136,10 | 2,48 | 219,01 | 22,39 | 2,17 | 2,01 | 61,76 |
| | 4 | 129,01 | 2,48 | 212,23 | 39,80 | 2,18 | 1,95 | 60,38 |
| | 5 | 150,05 | 2,52 | 203,88 | 31,89 | 2,12 | 1,94 | 73,32 |
| | Mean value | 132,63 | 2,44 | 210,00 | 28,56 | 2,14 | 1,93 | **62,85** |
| 4 | 1 | 148,39 | 2,35 | 325,65 | 33,73 | 2,18 | 2,19 | 45,20 |
| | 2 | 134,08 | 2,45 | 299,32 | 69,27 | 2,24 | 1,98 | 44,38 |
| | 3 | 171,31 | 2,58 | 315,48 | 24,13 | 2,20 | 2,04 | 53,98 |
| | 4 | 113,78 | 2,33 | 295,47 | 55,22 | 2,27 | 2,15 | 38,03 |
| | 5 | 118,74 | 2,46 | 325,32 | 17,40 | 2,22 | 2,06 | 36,06 |
| | Mean value | 137,26 | 2,43 | 312,25 | 39,95 | 2,22 | 2,08 | **43,53** |
| 2 | 1 | 105,97 | 2,57 | 624,94 | 14,26 | 2,38 | 2,66 | 16,64 |
| | 2 | 273,87 | 3,07 | 612,20 | 34,97 | 1,67 | 2,23 | 44,58 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 3 | 111,60 | 2,53 | 596,21 | 29,80 | 2,48 | 2,17 | 18,38 |
| | 4 | 245,76 | 2,90 | 634,02 | 13,51 | 2,32 | 2,08 | 38,54 |
| | 5 | 78,30 | 2,31 | 646,92 | 70,81 | 2,58 | 2,19 | 11,75 |
| | Mean value | 163,10 | 2,68 | 622,86 | 32,67 | 2,29 | 2,27 | **25,98** |

*Table C.1.2. Concentration results for velocity 0,12 m/s in the wind tunnel*

## C.1.3. Seat cover, top part, angle 60°, velocity 0,09 m/s in wind tunnel. Seat position 0 °

| *Concentration results for seat cover top part for velocity 0,09 m/s in the wind tunnel* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Supply airflow* | *Measurement No.* | *Monkey's nose* $C_{exp,PV}$ | *Near permeable wall* | *Supply PV diffuser* $C_{PV}$ | *On the anemometer* | *Laboratory* $C_{lab}$ | *Leakage from the gas bottle* | *Effectiveness* $\varepsilon_{PV}$ |
| [l/s] | [-] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [-] |
| 14 | 1 | 48,33 | 10,42 | 83,81 | 19,60 | 10,59 | 11,18 | 51,54 |
| | 2 | 64,87 | 10,76 | 83,62 | 19,92 | 10,89 | 11,48 | 74,22 |
| | 3 | 61,44 | 11,13 | 92,38 | 20,17 | 9,65 | 10,57 | 62,60 |
| | 4 | 45,15 | 9,92 | 89,74 | 17,80 | 10,12 | 10,13 | 44,00 |
| | 5 | 39,45 | 10,23 | 89,24 | 12,67 | 10,39 | 11,09 | 36,85 |
| | Mean value | 51,85 | 10,49 | 87,76 | 18,03 | 10,33 | 10,89 | **53,84** |
| 12 | 1 | 21,04 | 6,48 | 99,50 | 11,02 | 6,79 | 7,53 | 15,37 |
| | 2 | 19,50 | 6,99 | 89,86 | 15,83 | 7,46 | 12,45 | 14,61 |
| | 3 | 44,96 | 7,56 | 99,73 | 13,84 | 7,69 | 8,59 | 40,49 |
| | 4 | 46,07 | 7,86 | 95,25 | 15,10 | 8,10 | 9,32 | 43,57 |
| | 5 | 55,78 | 8,31 | 99,33 | 18,33 | 8,60 | 9,00 | 52,00 |
| | Mean value | 37,47 | 7,44 | 96,73 | 14,82 | 7,73 | 9,38 | **33,21** |

*Table C.1.3. Concentration results for velocity 0,09 m/s in the wind tunnel*

## C.1.4. Seat cover, top part, angle 60°, velocity 0,10 m/s in wind tunnel. Seat position 180 °

| *Concentration results for seat cover top part for velocity 0,10 m/s in the wind tunnel* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Supply airflow* | *Measurement No.* | *Monkey's nose $C_{exp,PV}$* | *Near permeable wall* | *Supply PV diffuser $C_{PV}$* | *On the anemometer* | *Laboratory $C_{lab}$* | *Leakage from the gas bottle* | *Effectiveness $\varepsilon_{PV}$* |
| [l/s] | [-] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [-] |
| 14 | 1 | 59,19 | 2,21 | 84,65 | 16,51 | 2,56 | 2,72 | 68,99 |
| | 2 | 71,03 | 2,74 | 84,00 | 22,96 | 3,11 | 8,28 | 83,97 |
| | 3 | 59,14 | 3,15 | 91,59 | 20,79 | 3,35 | 3,39 | 63,23 |
| | 4 | 61,74 | 3,33 | 87,61 | 22,65 | 3,55 | 6,27 | 69,22 |
| | 5 | 59,31 | 3,65 | 90,97 | 23,79 | 4,06 | 4,73 | 63,57 |
| | Mean value | 62,08 | 3,02 | 87,76 | 21,34 | 3,33 | 5,08 | **69,79** |
| 12 | 1 | 69,14 | 4,72 | 97,92 | 23,16 | 4,94 | 6,03 | 69,05 |
| | 2 | 58,11 | 4,96 | 105,22 | 22,81 | 5,16 | 5,26 | 52,92 |
| | 3 | 45,51 | 5,44 | 100,21 | 11,25 | 5,32 | 6,90 | 42,35 |
| | 4 | 39,00 | 5,45 | 94,55 | 15,83 | 5,43 | 5,96 | 37,67 |
| | 5 | 39,03 | 5,55 | 93,35 | 23,34 | 5,75 | 6,75 | 37,99 |
| | Mean value | 50,16 | 5,22 | 98,25 | 19,28 | 5,32 | 6,18 | **48,00** |

*Table C.1.4. Concentration results for velocity 0,10 m/s in the wind tunnel*

## *C.2. Concentration results for measurements in the cabin section*

### C.2.1. Seat cover top part, MV

| *Concentration results for MV top part* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Supply airflow* | *Measurement No.* | *Supply air upper nozzle* $c_0$ | *Exhaust pipe* $C_R$ | *Monkey's nose* $C_{exp}$ | *Laboratory* $C_{lab}$ | *160cm above the floor* | *190cm above the floor* | *Ventilation index* $\varepsilon_p$ | *Air quality index* $\varepsilon_{oz}$ |
| [l/s] | [-] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [-] | [-] |
| 20 | 1 | 0,66 | 61,47 | 67,03 | 4,33 | 70,56 | 76,66 | 0,92 | 0,83 |
| | 2 | 1,15 | 62,05 | 64,28 | 3,62 | 90,40 | 78,96 | 0,96 | 0,72 |
| | 3 | 1,31 | 63,01 | 67,92 | 1,49 | 80,54 | 77,18 | 0,93 | 0,79 |
| | 4 | 1,30 | 63,21 | 67,63 | 4,19 | 82,82 | 72,47 | 0,93 | 0,80 |
| | 5 | 0,93 | 62,96 | 66,22 | 2,63 | 93,36 | 80,55 | 0,95 | 0,72 |
| | 6 | 1,26 | 64,24 | 70,21 | 2,34 | 72,82 | 78,75 | 0,91 | 0,84 |
| | 7 | 0,94 | 64,21 | 66,80 | 3,04 | 90,73 | 81,44 | 0,96 | 0,74 |
| | 8 | 0,76 | 65,00 | 65,39 | 3,11 | 70,96 | 75,03 | 0,99 | 0,88 |
| | 9 | 1,31 | 63,01 | 70,13 | 2,02 | 88,88 | 78,74 | 0,90 | 0,74 |
| | 10 | 1,32 | 64,35 | 68,07 | 2,26 | 86,00 | 74,33 | 0,94 | 0,79 |
| | mean value | 1,09 | 63,35 | 67,37 | 2,90 | 82,71 | 77,41 | **0,94** | **0,79** |
| 15 | 1 | 1,19 | 54,94 | 57,52 | 2,03 | 57,42 | 72,42 | 0,95 | 0,84 |
| | 2 | 1,11 | 54,80 | 56,25 | 1,87 | 63,01 | 71,76 | 0,97 | 0,80 |
| | 3 | 1,13 | 54,80 | 56,76 | 2,00 | 68,51 | 68,91 | 0,96 | 0,79 |
| | 4 | 1,15 | 54,04 | 56,41 | 2,11 | 61,24 | 62,71 | 0,96 | 0,86 |
| | 5 | 1,15 | 53,38 | 55,84 | 2,23 | 54,58 | 81,82 | 0,96 | 0,77 |
| | 6 | 1,25 | 52,50 | 55,69 | 2,45 | 60,26 | 63,13 | 0,94 | 0,84 |
| | 7 | 1,12 | 51,88 | 52,80 | 2,68 | 54,72 | 65,28 | 0,98 | 0,85 |
| | 8 | 1,12 | 51,41 | 54,74 | 2,09 | 59,39 | 71,20 | 0,94 | 0,78 |
| | 9 | 1,20 | 50,81 | 52,31 | 2,96 | 55,50 | 68,32 | 0,97 | 0,81 |
| | 10 | 1,07 | 49,81 | 54,34 | 2,50 | 55,39 | 65,57 | 0,91 | 0,81 |
| | mean value | 1,15 | 52,84 | 55,27 | 2,29 | 59,00 | 69,11 | **0,96** | **0,82** |
| 10 | 1 | 0,93 | 92,34 | 92,99 | 4,45 | 123,41 | 123,11 | 0,99 | 0,74 |
| | 2 | 0,86 | 93,78 | 95,40 | 6,73 | 141,89 | 119,69 | 0,98 | 0,71 |
| | 3 | 0,92 | 94,60 | 97,53 | 5,34 | 142,31 | 117,48 | 0,97 | 0,72 |
| | 4 | 0,83 | 96,54 | 95,94 | 5,33 | 147,56 | 132,08 | 1,01 | 0,69 |
| | 5 | 0,91 | 96,51 | 100,07 | 4,90 | 134,94 | 130,69 | 0,96 | 0,72 |
| | 6 | 0,86 | 97,16 | 97,44 | 7,53 | 132,70 | 127,38 | 1,00 | 0,74 |
| | 7 | 0,96 | 97,93 | 98,25 | 5,97 | 143,45 | 140,09 | 1,00 | 0,69 |
| | 8 | 0,99 | 97,94 | 98,80 | 3,26 | 147,53 | 147,80 | 0,99 | 0,66 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 9 | 0,90 | 100,00 | 100,92 | 5,77 | 151,62 | 132,10 | 0,99 | 0,70 |
| | 10 | 0,94 | 99,92 | 102,03 | 4,85 | 158,72 | 133,13 | 0,98 | 0,68 |
| | mean value | 0,91 | 96,67 | 97,94 | 5,41 | 142,41 | 130,36 | **0,99** | **0,71** |

*Table C.2.1. Concentration results for mixing ventilation, seat cover*

## C.2.2. Seat cover, top part, DV

| *Concentration results for DV top part* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Supply airflow* | *Measurement No.* | *Return air nozzle* | *Exhaust pipe $C_R$* | *Monkey's nose $C_{exp}$* | *Laboratory $C_{lab}$* | *160cm above the floor* | *190cm above the floor* | *Ventilation index $\varepsilon_p$* | *Air quality index $\varepsilon_{oz}$* |
| [l/s] | [-] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [-] | [-] |
| 20 | 1 | 54,87 | 58,67 | 106,66 | 1,41 | 27,67 | 35,19 | 0,55 | 1,87 |
| | 2 | 48,07 | 62,44 | 66,62 | 1,38 | 26,61 | 34,92 | 0,94 | 2,03 |
| | 3 | 48,90 | 62,61 | 51,41 | 1,84 | 28,33 | 50,22 | 1,22 | 1,59 |
| | 4 | 53,45 | 59,33 | 105,31 | 2,29 | 28,16 | 32,96 | 0,56 | 1,94 |
| | 5 | 73,11 | 60,54 | 80,32 | 1,44 | 42,46 | 42,39 | 0,75 | 1,43 |
| | 6 | 47,09 | 59,27 | 72,12 | 2,01 | 31,12 | 56,12 | 0,82 | 1,36 |
| | 7 | 48,08 | 60,52 | 115,38 | 2,06 | 32,99 | 54,11 | 0,52 | 1,39 |
| | 8 | 53,45 | 60,44 | 51,81 | 1,78 | 33,39 | 43,33 | 1,17 | 1,58 |
| | 9 | 40,97 | 60,37 | 76,87 | 1,64 | 29,20 | 43,01 | 0,79 | 1,67 |
| | 10 | 44,06 | 59,62 | 47,17 | 1,38 | 33,05 | 44,66 | 1,26 | 1,53 |
| | mean value | 51,21 | 60,38 | 77,37 | 1,72 | 31,30 | 43,69 | **0,86** | **1,64** |
| 15 | 1 | 59,05 | 64,56 | 47,21 | 1,89 | 73,06 | 42,74 | 1,37 | 1,12 |
| | 2 | 54,14 | 65,62 | 69,19 | 2,00 | 75,01 | 46,43 | 0,95 | 1,08 |
| | 3 | 46,10 | 66,10 | 49,73 | 2,05 | 76,81 | 67,44 | 1,33 | 0,92 |
| | 4 | 45,19 | 63,31 | 52,97 | 1,88 | 71,35 | 63,96 | 1,20 | 0,94 |
| | 5 | 47,26 | 59,48 | 68,14 | 1,94 | 63,12 | 57,01 | 0,87 | 0,99 |
| | 6 | 45,02 | 64,68 | 52,16 | 1,99 | 63,11 | 42,26 | 1,24 | 1,23 |
| | 7 | 44,76 | 62,83 | 60,88 | 2,03 | 67,26 | 60,50 | 1,03 | 0,98 |
| | 8 | 47,21 | 63,52 | 66,93 | 2,01 | 76,89 | 62,73 | 0,95 | 0,91 |
| | 9 | 55,63 | 59,30 | 47,77 | 1,95 | 61,56 | 61,53 | 1,24 | 0,96 |
| | 10 | 44,56 | 64,07 | 56,29 | 1,96 | 63,83 | 75,77 | 1,14 | 0,92 |
| | mean value | 48,89 | 63,35 | 57,13 | 1,97 | 69,20 | 58,04 | **1,13** | **1,00** |
| 10 | 1 | 91,96 | 81,97 | 80,97 | 1,10 | 138,49 | 141,77 | 1,01 | 0,58 |
| | 2 | 82,43 | 76,27 | 64,50 | 1,10 | 141,31 | 144,12 | 1,18 | 0,53 |
| | 3 | 95,09 | 76,92 | 74,37 | 1,24 | 142,01 | 146,84 | 1,03 | 0,53 |
| | 4 | 76,30 | 78,35 | 77,90 | 4,69 | 147,26 | 149,04 | 1,01 | 0,53 |
| | 5 | 88,57 | 80,54 | 76,31 | 3,65 | 148,40 | 147,94 | 1,06 | 0,54 |
| | 6 | 99,41 | 85,93 | 73,31 | 2,92 | 150,46 | 157,76 | 1,17 | 0,56 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 7 | 74,29 | 82,61 | 74,04 | 3,53 | 150,32 | 157,19 | 1,12 | 0,54 |
| | 8 | 105,73 | 82,00 | 65,42 | 2,25 | 142,11 | 141,86 | 1,25 | 0,58 |
| | 9 | 82,78 | 83,99 | 68,52 | 2,15 | 155,16 | 155,67 | 1,23 | 0,54 |
| | 10 | 106,15 | 85,21 | 68,17 | 3,21 | 155,37 | 160,91 | 1,25 | 0,54 |
| | mean value | 90,27 | 81,38 | 72,35 | 2,58 | 147,09 | 150,31 | **1,13** | **0,55** |

*Table C.2.2. Concentration results for displacement ventilation, seat cover*

## C.2.3. Seat cover, top part, MV+PV

| ***Concentration results for MV+PV top part*** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Supply airflow from upper nozzle* | *Supply airflow from PV* | *No.* | *Supply air upper nozzle $C_0$* | *Supply PV diffuser $C_{PV}$* | *Exhaust pipe $C_R$* | *Monkey's nose $C_{exp,PV}$* | *Laboratory $C_{lab}$* | *170cm above the floor* | *Ventilation index for system $\varepsilon_{exp,system}$* | *Air quality index $\varepsilon_{oz}$* |
| [l/s] | [l/s] | [-] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [-] | [-] |
| 5 | 5 | 1 | 0,82 | 0,92 | 109,08 | 122,02 | 2,87 | 116,18 | 0,89 | 0,94 |
| | | 2 | 0,76 | 0,90 | 111,17 | 126,62 | 2,51 | 124,07 | 0,88 | 0,90 |
| | | 3 | 0,85 | 0,92 | 113,00 | 122,88 | 4,03 | 147,61 | 0,92 | 0,76 |
| | | 4 | 0,88 | 0,92 | 112,18 | 123,98 | 3,62 | 133,81 | 0,90 | 0,84 |
| | | 5 | 0,89 | 0,88 | 110,40 | 127,69 | 2,92 | 113,98 | 0,86 | 0,97 |
| | | 6 | 0,76 | 0,91 | 111,25 | 124,64 | 3,08 | 166,61 | 0,89 | 0,67 |
| | | 7 | 0,96 | 0,96 | 112,35 | 122,36 | 2,87 | 140,01 | 0,92 | 0,80 |
| | | 8 | 0,89 | 0,86 | 110,71 | 124,71 | 2,31 | 118,03 | 0,89 | 0,94 |
| | | 9 | 0,80 | 0,87 | 111,66 | 124,05 | 2,63 | 146,25 | 0,90 | 0,76 |
| | | 10 | 0,90 | 0,81 | 113,55 | 124,64 | 2,22 | 147,69 | 0,91 | 0,77 |
| | | mean value | 0,85 | 0,90 | 111,54 | 124,36 | 2,91 | 135,42 | **0,90** | **0,83** |
| 10 | 10 | 1 | 0,51 | 1,18 | 52,71 | 54,79 | 2,68 | 61,84 | 0,96 | 0,85 |
| | | 2 | 0,57 | 1,14 | 53,85 | 49,09 | 3,30 | 34,46 | 1,10 | 1,57 |
| | | 3 | 0,49 | 1,13 | 52,96 | 52,16 | 4,56 | 36,16 | 1,02 | 1,47 |
| | | 4 | 0,51 | 1,16 | 52,40 | 33,66 | 4,41 | 54,64 | 1,57 | 0,96 |
| | | 5 | 0,56 | 1,06 | 53,58 | 55,82 | 3,02 | 35,05 | 0,96 | 1,54 |
| | | 6 | 0,48 | 1,06 | 54,02 | 59,00 | 3,20 | 40,14 | 0,91 | 1,35 |
| | | 7 | 0,49 | 1,02 | 53,18 | 57,55 | 2,85 | 42,85 | 0,92 | 1,24 |
| | | 8 | 0,50 | 0,96 | 54,53 | 52,38 | 3,61 | 47,29 | 1,04 | 1,15 |
| | | 9 | 0,52 | 1,12 | 53,79 | 46,83 | 3,96 | 41,49 | 1,15 | 1,30 |
| | | 10 | 0,52 | 0,99 | 54,76 | 55,28 | 3,71 | 39,66 | 0,99 | 1,39 |
| | | mean value | 0,52 | 1,08 | 53,58 | 51,66 | 3,53 | 43,36 | **1,06** | **1,28** |
| 12 | 3 | 1 | 1,00 | 1,22 | 68,31 | 70,91 | 1,56 | 84,99 | 0,96 | 0,80 |
| | | 2 | 0,97 | 1,21 | 69,57 | 72,61 | 1,55 | 87,71 | 0,96 | 0,79 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 3 | 1,00 | 1,23 | 69,20 | 70,52 | 1,54 | 85,75 | 0,98 | 0,80 |
| | | 4 | 1,23 | 1,17 | 69,08 | 70,88 | 1,43 | 82,74 | 0,97 | 0,83 |
| | | 5 | 1,07 | 1,22 | 69,00 | 70,39 | 1,62 | 90,23 | 0,98 | 0,76 |
| | | 6 | 0,96 | 1,17 | 69,42 | 67,76 | 1,63 | 95,48 | 1,02 | 0,72 |
| | | 7 | 0,90 | 1,18 | 70,14 | 72,20 | 2,17 | 85,01 | 0,97 | 0,82 |
| | | 8 | 1,01 | 1,18 | 71,09 | 72,26 | 1,67 | 92,74 | 0,98 | 0,76 |
| | | 9 | 1,13 | 1,10 | 70,61 | 72,97 | 1,70 | 91,95 | 0,97 | 0,77 |
| | | 10 | 1,14 | 1,30 | 70,63 | 71,57 | 1,44 | 87,38 | 0,99 | 0,81 |
| | | mean value | 1,04 | 1,20 | 69,71 | 71,21 | 1,63 | 88,40 | **0,98** | **0,79** |
| 10 | 5 | 1 | 0,88 | 1,03 | 68,53 | 69,92 | 1,45 | 78,68 | 0,98 | 0,87 |
| | | 2 | 0,90 | 1,07 | 68,75 | 66,80 | 1,49 | 86,93 | 1,03 | 0,79 |
| | | 3 | 0,90 | 1,03 | 68,32 | 68,41 | 1,64 | 84,93 | 1,00 | 0,80 |
| | | 4 | 0,99 | 1,04 | 68,86 | 70,24 | 1,44 | 80,94 | 0,98 | 0,85 |
| | | 5 | 0,82 | 1,02 | 68,81 | 71,98 | 1,57 | 84,38 | 0,96 | 0,81 |
| | | 6 | 0,85 | 1,05 | 68,44 | 70,43 | 1,49 | 80,44 | 0,97 | 0,85 |
| | | 7 | 1,02 | 1,08 | 68,98 | 71,72 | 1,38 | 88,41 | 0,96 | 0,78 |
| | | 8 | 1,01 | 1,04 | 69,25 | 70,26 | 1,80 | 79,44 | 0,99 | 0,87 |
| | | 9 | 0,89 | 1,13 | 69,30 | 70,82 | 1,48 | 80,67 | 0,98 | 0,86 |
| | | 10 | 0,92 | 1,09 | 68,78 | 72,25 | 1,79 | 84,90 | 0,95 | 0,81 |
| | | mean value | 0,92 | 1,06 | 68,80 | 70,28 | 1,55 | 82,97 | **0,98** | **0,83** |
| 7 | 8 | 1 | 0,94 | 1,22 | 69,93 | 74,68 | 1,43 | 80,31 | 0,94 | 0,87 |
| | | 2 | 1,09 | 1,11 | 69,16 | 57,00 | 1,42 | 100,57 | 1,22 | 0,68 |
| | | 3 | 0,91 | 1,20 | 69,22 | 64,38 | 1,53 | 82,86 | 1,08 | 0,83 |
| | | 4 | 0,88 | 1,10 | 70,54 | 69,17 | 1,42 | 74,61 | 1,02 | 0,94 |
| | | 5 | 1,04 | 1,11 | 69,92 | 67,61 | 1,52 | 78,52 | 1,03 | 0,89 |
| | | 6 | 0,93 | 1,20 | 69,73 | 63,66 | 1,54 | 86,99 | 1,10 | 0,80 |
| | | 7 | 0,86 | 1,11 | 69,50 | 67,36 | 1,39 | 79,79 | 1,03 | 0,87 |
| | | 8 | 1,03 | 1,02 | 69,66 | 67,69 | 1,45 | 81,99 | 1,03 | 0,85 |
| | | 9 | 0,86 | 1,13 | 69,99 | 68,38 | 1,42 | 79,84 | 1,02 | 0,88 |
| | | 10 | 0,90 | 1,10 | 70,05 | 68,22 | 2,22 | 79,13 | 1,03 | 0,88 |
| | | mean value | 0,94 | 1,13 | 69,77 | 66,82 | 1,53 | 82,46 | **1,05** | **0,85** |
| 5 | 10 | 1 | 0,65 | 0,49 | 82,71 | 78,11 | 1,55 | 88,36 | 1,06 | 0,94 |
| | | 2 | 0,68 | 0,52 | 80,67 | 84,41 | 1,81 | 85,43 | 0,96 | 0,94 |
| | | 3 | 0,66 | 0,50 | 81,42 | 70,71 | 1,26 | 116,83 | 1,15 | 0,70 |
| | | 4 | 0,76 | 0,51 | 80,83 | 55,52 | 1,26 | 99,84 | 1,46 | 0,81 |
| | | 5 | 0,70 | 0,49 | 81,81 | 84,07 | 1,76 | 68,00 | 0,97 | 1,21 |
| | | 6 | 0,62 | 0,51 | 81,55 | 52,03 | 2,30 | 85,13 | 1,57 | 0,96 |
| | | 7 | 0,66 | 0,50 | 82,62 | 71,30 | 3,19 | 88,74 | 1,16 | 0,93 |
| | | 8 | 0,65 | 0,56 | 81,35 | 84,88 | 4,27 | 79,26 | 0,96 | 1,03 |
| | | 9 | 0,69 | 0,66 | 79,68 | 51,64 | 4,62 | 82,84 | 1,55 | 0,96 |
| | | 10 | 0,57 | 0,63 | 81,21 | 62,43 | 6,10 | 93,06 | 1,30 | 0,87 |
| | | mean value | 0,66 | 0,54 | 81,39 | 69,51 | 2,81 | 88,75 | **1,21** | **0,93** |
| 3 | 12 | 1 | 1,03 | 1,29 | 66,10 | 66,97 | 1,77 | 88,15 | 0,99 | 0,75 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 2 | 0,99 | 1,26 | 66,36 | 45,07 | 1,75 | 89,78 | 1,48 | 0,74 |
| | | 3 | 0,96 | 1,31 | 66,58 | 50,01 | 1,73 | 79,62 | 1,34 | 0,83 |
| | | 4 | 0,94 | 1,27 | 66,03 | 14,25 | 1,69 | 75,35 | 4,89 | 0,87 |
| | | 5 | 0,84 | 1,15 | 66,23 | 69,15 | 1,74 | 91,70 | 0,96 | 0,72 |
| | | 6 | 0,94 | 1,23 | 65,89 | 65,13 | 1,59 | 91,54 | 1,01 | 0,72 |
| | | 7 | 0,87 | 1,13 | 65,29 | 50,56 | 1,58 | 88,87 | 1,30 | 0,73 |
| | | 8 | 1,02 | 1,06 | 65,39 | 65,11 | 1,52 | 79,72 | 1,00 | 0,82 |
| | | 9 | 0,89 | 1,15 | 65,61 | 65,05 | 1,71 | 87,25 | 1,01 | 0,75 |
| | | 10 | 1,00 | 1,20 | 65,28 | 48,11 | 1,81 | 94,95 | 1,36 | 0,68 |
| | | mean value | 0,95 | 1,21 | 65,88 | 53,94 | 1,69 | 86,69 | **1,53** | **0,76** |

*Table C.2.3. Concentration results for combined ventilation (MV+PV), seat cover top part*

## C.2.4. Seat cover, top part, DV+PV

| *Concentration results for DV+PV top part* | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Supply airflow from upper nozzle* | *Supply airflow from PV* | *No.* | *Return air nozzle* | *Supply PV diffuser $C_{PV}$* | *Exhaust pipe $C_R$* | *Monkey's nose $C_{exp,PV}$* | *Laboratory $C_{lab}$* | *170cm above the floor* | *Ventilation index for system $\varepsilon_{exp,system}$* | *Air quality index $\varepsilon_{oz}$* |
| [l/s] | [l/s] | [-] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [-] | [-] |
| 5 | 5 | 1 | 81,78 | 1,26 | 71,79 | 79,41 | 3,03 | 121,98 | 0,90 | 0,59 |
| | | 2 | 85,24 | 1,33 | 69,77 | 69,22 | 4,88 | 120,41 | 1,01 | 0,58 |
| | | 3 | 74,73 | 1,28 | 72,34 | 68,85 | 4,56 | 119,93 | 1,05 | 0,60 |
| | | 4 | 76,89 | 1,40 | 69,87 | 60,79 | 3,65 | 145,13 | 1,15 | 0,48 |
| | | 5 | 69,90 | 1,37 | 70,83 | 62,26 | 3,53 | 132,99 | 1,14 | 0,53 |
| | | 6 | 74,80 | 1,47 | 71,79 | 74,83 | 5,02 | 132,72 | 0,96 | 0,54 |
| | | 7 | 74,95 | 1,38 | 71,90 | 83,67 | 6,56 | 143,75 | 0,86 | 0,50 |
| | | 8 | 78,17 | 1,37 | 68,66 | 66,75 | 5,39 | 128,13 | 1,03 | 0,54 |
| | | 9 | 77,82 | 1,34 | 69,11 | 75,39 | 5,38 | 126,10 | 0,92 | 0,55 |
| | | 10 | 79,38 | 1,,43 | 70,22 | 70,69 | 5,29 | 126,20 | 0,99 | 0,56 |
| | | mean value | 77,37 | 1,36 | 70,63 | 71,19 | 4,73 | 129,73 | **1,00** | **0,55** |
| 5 | 10 | 1 | 55,69 | 1,73 | 54,23 | 63,73 | 7,53 | 114,60 | 0,85 | 0,47 |
| | | 2 | 53,78 | 1,73 | 55,52 | 23,21 | 4,16 | 116,40 | 2,39 | 0,48 |
| | | 3 | 53,90 | 1,88 | 53,09 | 55,41 | 5,74 | 115,68 | 0,96 | 0,46 |
| | | 4 | 50,97 | 1,80 | 55,22 | 55,70 | 4,27 | 111,62 | 0,99 | 0,49 |
| | | 5 | 54,44 | 1,56 | 53,36 | 36,64 | 4,89 | 113,14 | 1,46 | 0,47 |
| | | 6 | 56,95 | 1,98 | 53,98 | 59,29 | 6,76 | 110,13 | 0,91 | 0,49 |
| | | 7 | 60,00 | 1,64 | 53,50 | 59,22 | 5,67 | 109,01 | 0,90 | 0,49 |
| | | 8 | 60,77 | 1,61 | 53,62 | 59,88 | 5,25 | 122,33 | 0,90 | 0,44 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 9 | 54,36 | 1,65 | 54,74 | 49,10 | 6,17 | 121,14 | 1,11 | 0,45 |
| | | 10 | 50,70 | 1,58 | 54,02 | 59,38 | 5,68 | 110,96 | 0,91 | 0,49 |
| | | mean value | 55,16 | 1,72 | 54,13 | 52,16 | 5,61 | 114,50 | **1,14** | **0,47** |
| 15 | 5 | 1 | 40,54 | 1,39 | 45,99 | 56,83 | 6,17 | 86,62 | 0,81 | 0,53 |
| | | 2 | 45,56 | 1,40 | 46,06 | 57,56 | 3,94 | 89,38 | 0,80 | 0,52 |
| | | 3 | 52,56 | 1,46 | 47,53 | 55,32 | 5,12 | 67,27 | 0,86 | 0,71 |
| | | 4 | 46,18 | 1,44 | 48,77 | 39,86 | 15,73 | 58,04 | 1,22 | 0,84 |
| | | 5 | 56,84 | 1,44 | 47,18 | 55,70 | 7,33 | 78,78 | 0,85 | 0,60 |
| | | 6 | 43,71 | 1,37 | 46,60 | 69,75 | 10,04 | 83,85 | 0,67 | 0,56 |
| | | 7 | 50,85 | 1,43 | 46,37 | 75,35 | 6,68 | 80,02 | 0,62 | 0,58 |
| | | 8 | 42,20 | 1,34 | 47,73 | 85,63 | 10,31 | 78,74 | 0,56 | 0,61 |
| | | 9 | 37,30 | 1,39 | 47,24 | 54,30 | 10,38 | 76,97 | 0,87 | 0,61 |
| | | 10 | 39,30 | 1,41 | 47,73 | 48,90 | 9,12 | 77,32 | 0,98 | 0,62 |
| | | mean value | 45,50 | 1,41 | 47,12 | 59,92 | 8,48 | 77,70 | **0,82** | **0,62** |
| 12 | 8 | 1 | 41,43 | 1,62 | 48,01 | 51,10 | 1,70 | 142,44 | 0,94 | 0,34 |
| | | 2 | 44,57 | 1,54 | 52,48 | 22,03 | 1,66 | 129,73 | 2,38 | 0,40 |
| | | 3 | 45,19 | 1,54 | 49,50 | 27,10 | 1,60 | 126,76 | 1,83 | 0,39 |
| | | 4 | 44,26 | 1,50 | 51,31 | 42,37 | 1,57 | 119,52 | 1,21 | 0,43 |
| | | 5 | 43,26 | 1,44 | 51,54 | 45,31 | 1,49 | 104,27 | 1,14 | 0,49 |
| | | 6 | 55,61 | 1,52 | 51,01 | 43,65 | 1,69 | 111,34 | 1,17 | 0,46 |
| | | 7 | 45,55 | 1,43 | 51,60 | 40,83 | 1,61 | 131,85 | 1,26 | 0,39 |
| | | 8 | 44,38 | 1,34 | 52,39 | 43,52 | 1,52 | 128,17 | 1,20 | 0,41 |
| | | 9 | 42,59 | 1,33 | 48,82 | 35,79 | 1,44 | 126,87 | 1,36 | 0,38 |
| | | 10 | 47,69 | 1,31 | 50,49 | 35,79 | 1,47 | 123,78 | 1,41 | 0,41 |
| | | mean value | 45,45 | 1,46 | 50,72 | 38,75 | 1,58 | 124,47 | **1,39** | **0,41** |
| 10 | 10 | 1 | 37,00 | 1,00 | 36,63 | 35,27 | 5,15 | 103,72 | 1,04 | 0,35 |
| | | 2 | 39,19 | 1,06 | 38,63 | 22,83 | 4,12 | 107,82 | 1,69 | 0,36 |
| | | 3 | 37,57 | 1,19 | 37,84 | 17,36 | 2,68 | 94,24 | 2,18 | 0,40 |
| | | 4 | 39,98 | 1,26 | 40,02 | 18,65 | 3,44 | 114,19 | 2,15 | 0,35 |
| | | 5 | 33,18 | 1,33 | 41,13 | 20,13 | 6,28 | 108,84 | 2,04 | 0,38 |
| | | 6 | 47,13 | 1,28 | 40,51 | 19,77 | 5,42 | 118,52 | 2,05 | 0,34 |
| | | 7 | 41,19 | 1,40 | 40,76 | 22,99 | 4,96 | 105,97 | 1,77 | 0,38 |
| | | 8 | 47,87 | 1,37 | 40,81 | 35,23 | 3,14 | 113,61 | 1,16 | 0,36 |
| | | 9 | 40,84 | 1,47 | 39,96 | 41,30 | 8,96 | 112,04 | 0,97 | 0,36 |
| | | 10 | 37,83 | 1,38 | 39,90 | 60,65 | 5,97 | 110,36 | 0,66 | 0,36 |
| | | mean value | 40,18 | 1,27 | 39,62 | 29,42 | 5,01 | 108,93 | **1,57** | **0,36** |
| 7 | 13 | 1 | 40,13 | 1,74 | 45,93 | 7,55 | 2,22 | 146,91 | 6,08 | 0,31 |
| | | 2 | 41,29 | 1,66 | 46,00 | 5,01 | 1,67 | 87,76 | 9,18 | 0,52 |
| | | 3 | 42,40 | 1,61 | 47,72 | 6,65 | 1,67 | 124,43 | 7,18 | 0,38 |
| | | 4 | 39,29 | 1,64 | 47,63 | 7,57 | 1,95 | 125,44 | 6,29 | 0,38 |
| | | 5 | 37,13 | 1,64 | 43,97 | 41,03 | 1,90 | 88,29 | 1,07 | 0,50 |
| | | 6 | 36,90 | 1,58 | 48,10 | 10,01 | 1,58 | 99,18 | 4,81 | 0,48 |
| | | 7 | 43,59 | 1,62 | 47,64 | 22,91 | 1,73 | 119,38 | 2,08 | 0,40 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 8 | 40,27 | 1,63 | 44,12 | 16,90 | 2,16 | 89,36 | 2,61 | 0,49 |
| | | 9 | 41,34 | 1,60 | 47,59 | 16,62 | 1,91 | 122,51 | 2,86 | 0,39 |
| | | 10 | 42,31 | 1,60 | 45,98 | 13,36 | 2,63 | 122,65 | 3,44 | 0,37 |
| | | mean value | 40,47 | 1,63 | 46,47 | 14,76 | 1,94 | 112,59 | **4,56** | **0,42** |
| 5 | 15 | 1 | 43,35 | 2,21 | 46,03 | 12,07 | 2,29 | 127,86 | 3,81 | 0,36 |
| | | 2 | 44,66 | 2,18 | 47,97 | 4,91 | 2,30 | 112,31 | 9,77 | 0,43 |
| | | 3 | 41,99 | 2,10 | 47,85 | 17,09 | 2,25 | 128,09 | 2,80 | 0,37 |
| | | 4 | 42,33 | 2,08 | 46,61 | 4,54 | 2,08 | 112,94 | 10,27 | 0,41 |
| | | 5 | 41,91 | 1,99 | 48,36 | 29,71 | 2,10 | 123,77 | 1,63 | 0,39 |
| | | 6 | 56,36 | 2,06 | 47,14 | 11,41 | 2,21 | 121,80 | 4,13 | 0,39 |
| | | 7 | 34,88 | 1,95 | 47,33 | 9,03 | 1,83 | 127,86 | 5,24 | 0,37 |
| | | 8 | 48,87 | 1,92 | 46,81 | 22,61 | 1,91 | 117,76 | 2,07 | 0,40 |
| | | 9 | 48,17 | 1,88 | 48,40 | 5,85 | 1,78 | 131,23 | 8,27 | 0,37 |
| | | 10 | 38,50 | 1,92 | 46,51 | 7,49 | 2,13 | 122,70 | 6,21 | 0,38 |
| | | mean value | 44,10 | 2,03 | 47,30 | 12,47 | 2,09 | 122,63 | **5,42** | **0,39** |

*Table C.2.4. Concentration results for combined ventilation (DV+PV), seat cover top part*

## C.2.5. Seat cover, middle part, MV+PV

| *Concentration results for MV+PV middle part* | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Supply airflow from upper nozzle* | *Supply airflow from PV* | *No.* | *Supply air upper nozzle $C_0$* | *Supply PV diffuser $C_{PV}$* | *Exhaust pipe $C_R$* | *Monkey's nose $C_{exp,PV}$* | *Laboratory $C_{lab}$* | *170cm above the floor* | *Ventilation index for system $\varepsilon_{exp,system}$* | *Air quality index $\varepsilon_{oz}$* |
| [l/s] | [l/s] | [-] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [-] | [-] |
| 3 | 12 | 1 | 1,36 | 2,00 | 44,22 | 53,40 | 3,17 | 115,52 | 0,82 | 0,38 |
| | | 2 | 1,33 | 2,07 | 44,93 | 52,36 | 2,70 | 128,63 | 0,85 | 0,34 |
| | | 3 | 1,39 | 2,21 | 43,74 | 52,07 | 3,40 | 126,28 | 0,84 | 0,34 |
| | | 4 | 1,30 | 2,16 | 44,97 | 52,24 | 3,43 | 126,46 | 0,86 | 0,35 |
| | | 5 | 1,41 | 2,10 | 45,30 | 52,36 | 2,62 | 121,18 | 0,86 | 0,37 |
| | | 6 | 1,40 | 2,37 | 44,81 | 59,08 | 3,01 | 123,27 | 0,75 | 0,36 |
| | | 7 | 1,24 | 2,01 | 43,87 | 54,25 | 2,11 | 103,03 | 0,80 | 0,42 |
| | | 8 | 1,22 | 1,91 | 43,39 | 53,56 | 2,05 | 103,26 | 0,81 | 0,41 |
| | | 9 | 1,31 | 2,23 | 43,88 | 54,66 | 5,08 | 139,09 | 0,80 | 0,31 |
| | | 10 | 1,45 | 2,47 | 43,45 | 52,39 | 2,96 | 112,40 | 0,82 | 0,38 |
| | | mean value | 1,34 | 2,15 | 44,26 | 53,64 | 3,05 | 119,91 | **0,82** | **0,36** |

*Table C.2.5. Concentration results for combined ventilation (MV+PV), seat cover middle part*

## C.2.6. Seat cover, middle part, DV+PV

| *Concentration results for DV+PV middle part* | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Supply airflow from upper nozzle* | *Supply airflow from PV* | *No.* | *Return air nozzle* | *Supply PV diffuser $C_{PV}$* | *Exhaust pipe $C_R$* | *Monkey's nose $C_{exp,PV}$* | *Laboratory $C_{lab}$* | *170cm above the floor* | *Ventilation index for system $\varepsilon_{exp,system}$* | *Air quality index $\varepsilon_{oz}$* |
| [l/s] | [l/s] | [-] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [-] | [-] |
| 5 | 15 | 1 | 47,15 | 1,47 | 54,40 | 40,70 | 1,68 | 116,41 | 1,34 | 0,47 |
| | | 2 | 59,80 | 1,54 | 58,27 | 40,80 | 1,63 | 92,86 | 1,43 | 0,63 |
| | | 3 | 51,75 | 1,53 | 56,95 | 40,10 | 1,67 | 102,35 | 1,42 | 0,56 |
| | | 4 | 43,49 | 1,40 | 57,16 | 42,00 | 2,04 | 116,85 | 1,36 | 0,49 |
| | | 5 | 48,59 | 1,44 | 57,81 | 41,36 | 1,57 | 113,52 | 1,40 | 0,51 |
| | | 6 | 50,68 | 1,15 | 57,91 | 36,52 | 2,70 | 107,50 | 1,59 | 0,54 |
| | | 7 | 54,14 | 1,42 | 55,08 | 46,30 | 1,69 | 106,66 | 1,19 | 0,52 |
| | | 8 | 57,95 | 1,53 | 59,92 | 45,45 | 1,64 | 99,45 | 1,32 | 0,60 |
| | | 9 | 56,38 | 1,49 | 56,20 | 42,41 | 2,00 | 95,08 | 1,33 | 0,59 |
| | | 10 | 51,45 | 1,47 | 57,38 | 42,89 | 1,74 | 105,16 | 1,34 | 0,55 |
| | | mean value | 52,14 | 1,44 | 57,11 | 41,85 | 1,84 | 105,58 | **1,37** | **0,54** |

*Table C.2.6. Concentration results for combined ventilation (DV+PV), seat cover middle part*

## C.2.7. Seat cover, both parts, MV+PV

| *Concentration results for MV+PV both parts* | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Supply airflow from upper nozzle* | *Supply airflow from PV* | *No.* | *Supply air upper nozzle $C_O$* | *Supply PV diffuser $C_{PV}$* | *Exhaust pipe $C_R$* | *Monkey's nose $C_{exp,PV}$* | *Laboratory $C_{lab}$* | *170cm above the floor* | *Ventilation index for system $\varepsilon_{exp,system}$* | *Air quality index $\varepsilon_{oz}$* |
| [l/s] | [l/s] | [-] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [-] | [-] |
| 3 | 12 | 1 | 0,86 | 1,63 | 53,05 | 47,98 | 1,30 | 124,47 | 1,11 | 0,42 |
| | | 2 | 0,93 | 1,30 | 52,08 | 50,18 | 1,58 | 106,36 | 1,04 | 0,49 |
| | | 3 | 0,80 | 1,62 | 52,83 | 49,07 | 1,42 | 101,21 | 1,08 | 0,52 |
| | | 4 | 0,76 | 1,89 | 52,23 | 50,32 | 4,23 | 88,89 | 1,04 | 0,58 |
| | | 5 | 1,01 | 1,17 | 52,66 | 50,20 | 1,96 | 96,27 | 1,05 | 0,54 |
| | | 6 | 0,90 | 1,24 | 52,60 | 52,04 | 2,53 | 130,72 | 1,01 | 0,40 |
| | | 7 | 1,00 | 1,28 | 52,30 | 25,63 | 1,47 | 120,73 | 2,08 | 0,43 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 8 | 0,96 | 1,07 | 52,42 | 43,77 | 3,82 | 119,27 | 1,20 | 0,43 |
| | | 9 | 0,91 | 1,24 | 52,83 | 36,52 | 2,64 | 112,68 | 1,46 | 0,46 |
| | | 10 | 1,00 | 1,16 | 53,07 | 38,76 | 1,93 | 109,46 | 1,38 | 0,48 |
| | | mean value | 0,91 | 1,36 | 52,61 | 44,45 | 2,29 | 111,01 | **1,24** | **0,48** |

*Table C.2.7. Concentration results for combined ventilation (MV+PV), seat cover both parts*

## C.2.8. Seat cover, both parts, DV+PV

| *Concentration results for DV+PV both parts* | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Supply airflow from upper nozzle* | *Supply airflow from PV* | *No.* | *Return air nozzle* | *Supply PV diffuser $C_{PV}$* | *Exhaust pipe $C_R$* | *Monkey's nose $C_{exp,PV}$* | *Laboratory $C_{lab}$* | *170cm above the floor* | *Ventilation index for system $\varepsilon_{exp,system}$* | *Air quality index $\varepsilon_{oz}$* |
| [l/s] | [l/s] | [-] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [-] | [-] |
| 5 | 15 | 1 | 38,84 | 1,83 | 45,03 | 29,63 | 2,65 | 141,21 | 1,52 | 0,32 |
| | | 2 | 47,56 | 1,77 | 42,61 | 37,93 | 4,42 | 169,05 | 1,12 | 0,25 |
| | | 3 | 37,23 | 1,76 | 45,73 | 48,84 | 3,71 | 143,87 | 0,94 | 0,32 |
| | | 4 | 39,26 | 1,89 | 43,86 | 36,97 | 3,33 | 143,78 | 1,19 | 0,31 |
| | | 5 | 48,99 | 1,85 | 44,12 | 33,64 | 2,66 | 125,40 | 1,31 | 0,35 |
| | | 6 | 39,77 | 1,85 | 43,24 | 36,31 | 2,59 | 122,60 | 1,19 | 0,35 |
| | | 7 | 48,18 | 2,17 | 43,23 | 34,11 | 2,74 | 158,56 | 1,27 | 0,27 |
| | | 8 | 37,75 | 1,93 | 47,29 | 36,09 | 2,80 | 158,41 | 1,31 | 0,30 |
| | | 9 | 41,85 | 1,91 | 41,11 | 37,16 | 2,95 | 160,68 | 1,11 | 0,26 |
| | | 10 | 44,60 | 1,90 | 43,92 | 51,36 | 3,96 | 152,07 | 0,86 | 0,29 |
| | | mean value | 42,40 | 1,89 | 44,01 | 38,20 | 3,18 | 147,56 | **1,18** | **0,30** |

*Table C.2.8. Concentration results for combined ventilation (DV+PV), seat cover both parts*

## C.2.9. Seat stap, top part, MV+PV

| Concentration results for MV+PV seat strap top part | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Supply airflow from upper nozzle* | *Supply airflow from PV* | *No.* | *Supply air upper nozzle $C_0$* | *Supply PV diffuser $C_{PV}$* | *Exhaust pipe $C_R$* | *Monkey's nose $C_{exp,PV}$* | *Laboratory $C_{lab}$* | *170cm above the floor* | *Ventilation index for system $\varepsilon_{exp,system}$* | *Air quality index $\varepsilon_{oz}$* |
| [l/s] | [l/s] | [-] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [-] | [-] |
| 3 | 12 | 1 | 0,66 | 1,64 | 52,82 | 26,64 | 0,72 | 61,09 | 2,01 | 0,86 |
| | | 2 | 0,80 | 1,03 | 53,80 | 39,88 | 0,83 | 58,62 | 1,36 | 0,92 |
| | | 3 | 0,68 | 1,02 | 52,37 | 32,70 | 0,97 | 49,90 | 1,61 | 1,05 |
| | | 4 | 0,88 | 1,19 | 53,34 | 11,45 | 0,74 | 57,57 | 4,96 | 0,93 |
| | | 5 | 0,92 | 1,80 | 52,67 | 42,64 | 0,87 | 61,47 | 1,24 | 0,85 |
| | | 6 | 0,68 | 0,81 | 52,20 | 45,04 | 0,78 | 59,07 | 1,16 | 0,88 |
| | | 7 | 0,67 | 1,40 | 53,65 | 31,82 | 0,74 | 74,18 | 1,70 | 0,72 |
| | | 8 | 1,22 | 1,31 | 53,94 | 48,60 | 0,81 | 55,75 | 1,11 | 0,97 |
| | | 9 | 0,76 | 1,73 | 52,85 | 49,09 | 0,88 | 67,43 | 1,08 | 0,78 |
| | | 10 | 0,70 | 1,90 | 53,24 | 36,23 | 0,92 | 33,09 | 1,48 | 1,62 |
| | | mean value | 0,80 | 1,38 | 53,09 | 36,41 | 0,83 | 57,82 | **1,77** | **0,96** |

*Table C.2.9. Concentration results for combined ventilation (MV+PV), seat strap top part*

## C.2.10. Seat stap, top part, DV+PV

| Concentration results for DV+PV top part | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Supply airflow from upper nozzle* | *Supply airflow from PV* | *No.* | *Return air nozzle* | *Supply PV diffuser $C_{PV}$* | *Exhaust pipe $C_R$* | *Monkey's nose $C_{exp,PV}$* | *Laboratory $C_{lab}$* | *170cm above the floor* | *Ventilation index for system $\varepsilon_{exp,system}$* | *Air quality index $\varepsilon_{oz}$* |
| [l/s] | [l/s] | [-] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [-] | [-] |
| 5 | 15 | 1 | 45,49 | 2,26 | 47,06 | 5,34 | 2,21 | 56,17 | 8,81 | 0,84 |
| | | 2 | 56,57 | 2,99 | 46,31 | 23,33 | 1,66 | 57,78 | 1,98 | 0,80 |
| | | 3 | 40,61 | 3,07 | 46,01 | 9,95 | 2,97 | 80,33 | 4,62 | 0,57 |
| | | 4 | 67,09 | 5,14 | 45,89 | 85,39 | 3,45 | 67,17 | 0,54 | 0,68 |
| | | 5 | 49,45 | 3,36 | 46,83 | 15,94 | 2,47 | 101,39 | 2,94 | 0,46 |
| | | 6 | 38,61 | 3,09 | 48,61 | 37,62 | 1,77 | 58,26 | 1,29 | 0,83 |
| | | 7 | 60,48 | 2,20 | 49,06 | 45,77 | 2,60 | 56,27 | 1,07 | 0,87 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 8 | 61,31 | 2,05 | 50,08 | 39,54 | 3,64 | 59,80 | 1,27 | 0,84 |
| | | 9 | 51,57 | 3,42 | 46,92 | 114,57 | 3,25 | 73,37 | 0,41 | 0,64 |
| | | 10 | 45,93 | 4,46 | 43,06 | 22,97 | 3,06 | 72,07 | 1,87 | 0,60 |
| | | mean value | 51,71 | 3,20 | 46,98 | 40,04 | 2,71 | 68,26 | **2,48** | **0,71** |

Table C.2.10. Concentration results for combined ventilation (DV+PV), seat strap top part

## C.2.11. Seat stap, middle part, MV+PV

| ***Concentration results for MV+PV seat strap middle part*** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Supply airflow from upper nozzle* | *Supply airflow from PV* | *No.* | *Supply air upper nozzle $C_0$* | *Supply PV diffuser $C_{PV}$* | *Exhaust pipe $C_R$* | *Monkey's nose $C_{exp,PV}$* | *Laboratory $C_{lab}$* | *170cm above the floor* | *Ventilation index for system $\varepsilon_{exp,system}$* | *Air quality index $\varepsilon_{oz}$* |
| [l/s] | [l/s] | [-] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [-] | [-] |
| 3 | 12 | 1 | 0,75 | 2,17 | 58,38 | 57,55 | 4,48 | 78,19 | 1,01 | 0,74 |
| | | 2 | 0,75 | 2,35 | 59,58 | 60,67 | 6,55 | 85,11 | 0,98 | 0,70 |
| | | 3 | 1,07 | 2,36 | 59,51 | 54,80 | 3,92 | 86,06 | 1,09 | 0,69 |
| | | 4 | 0,74 | 1,86 | 59,63 | 58,01 | 4,51 | 83,94 | 1,03 | 0,71 |
| | | 5 | 1,12 | 2,68 | 58,38 | 55,73 | 6,43 | 82,19 | 1,05 | 0,71 |
| | | 6 | 0,87 | 4,25 | 60,33 | 55,68 | 5,32 | 78,74 | 1,08 | 0,76 |
| | | 7 | 0,78 | 3,64 | 61,41 | 53,72 | 7,39 | 97,89 | 1,15 | 0,62 |
| | | 8 | 0,82 | 2,30 | 59,79 | 55,50 | 5,91 | 83,45 | 1,08 | 0,71 |
| | | 9 | 0,99 | 2,25 | 60,67 | 55,35 | 5,74 | 111,03 | 1,10 | 0,54 |
| | | 10 | 1,22 | 2,98 | 60,45 | 54,06 | 5,61 | 120,95 | 1,12 | 0,49 |
| | | mean value | 0,91 | 2,68 | 59,81 | 56,11 | 5,59 | 90,76 | **1,07** | **0,67** |

Table C.2.11. Concentration results for combined ventilation (MV+PV), seat strap middle part

## C.2.12. Seat stap, middle part, DV+PV

| Concentration results for DV+PV middle parts | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Supply airflow from upper nozzle | Supply airflow from PV | No. | Return air nozzle | Supply PV diffuser $C_{PV}$ | Exhaust pipe $C_R$ | Monkey's nose $C_{exp,PV}$ | Laboratory $C_{lab}$ | 170cm above the floor | Ventilation index for system $\varepsilon_{exp,system}$ | Air quality index $\varepsilon_{oz}$ |
| [l/s] | [l/s] | [-] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [-] | [-] |
| 5 | 15 | 1 | 24,81 | 1,12 | 54,81 | 40,03 | 2,18 | 78,02 | 1,37 | 0,70 |
| | | 2 | 27,20 | 1,00 | 55,11 | 36,70 | 4,31 | 84,06 | 1,50 | 0,66 |
| | | 3 | 24,68 | 1,05 | 58,04 | 38,40 | 3,84 | 93,53 | 1,51 | 0,62 |
| | | 4 | 29,56 | 0,83 | 55,96 | 22,49 | 2,17 | 91,42 | 2,49 | 0,61 |
| | | 5 | 26,92 | 1,04 | 55,84 | 28,25 | 3,96 | 87,97 | 1,98 | 0,63 |
| | | 6 | 23,94 | 2,16 | 54,39 | 38,84 | 4,86 | 91,95 | 1,40 | 0,59 |
| | | 7 | 26,04 | 2,24 | 55,58 | 33,72 | 5,40 | 100,87 | 1,65 | 0,55 |
| | | 8 | 32,59 | 1,83 | 54,04 | 39,63 | 3,27 | 90,35 | 1,36 | 0,60 |
| | | 9 | 49,73 | 1,53 | 55,19 | 40,13 | 5,96 | 89,60 | 1,38 | 0,62 |
| | | 10 | 27,91 | 2,45 | 56,93 | 33,01 | 3,45 | 90,78 | 1,72 | 0,63 |
| | | mean value | 29,34 | 1,53 | 55,59 | 35,12 | 3,94 | 89,86 | **1,64** | **0,62** |

*Table C.2.12. Concentration results for combined ventilation (DV+PV), seat strap middle part*

## C.2.13. Seat stap, both parts, MV+PV

| Concentration results for MV+PV seat strap both parts | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Supply airflow from upper nozzle | Supply airflow from PV | No. | Supply air upper nozzle $C_O$ | Supply PV diffuser $C_{PV}$ | Exhaust pipe $C_R$ | Monkey's nose $C_{exp,PV}$ | Laboratory $C_{lab}$ | 170cm above the floor | Ventilation index for system $\varepsilon_{exp,system}$ | Air quality index $\varepsilon_{oz}$ |
| [l/s] | [l/s] | [-] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [-] | [-] |
| 3 | 12 | 1 | 0,84 | 1,58 | 66,87 | 22,28 | 6,96 | 119,21 | 3,08 | 0,56 |
| | | 2 | 1,03 | 1,19 | 65,07 | 35,69 | 4,39 | 131,29 | 1,85 | 0,49 |
| | | 3 | 1,64 | 1,93 | 62,47 | 50,18 | 4,65 | 104,36 | 1,25 | 0,59 |
| | | 4 | 0,88 | 2,20 | 62,25 | 49,32 | 5,32 | 108,71 | 1,27 | 0,57 |
| | | 5 | 0,99 | 1,29 | 60,97 | 52,58 | 4,23 | 117,00 | 1,16 | 0,52 |
| | | 6 | 0,81 | 1,04 | 60,69 | 54,22 | 5,60 | 112,88 | 1,12 | 0,53 |
| | | 7 | 0,88 | 1,10 | 60,48 | 51,46 | 5,36 | 114,84 | 1,18 | 0,52 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 8 | 1,21 | 1,59 | 60,72 | 52,09 | 4,95 | 129,80 | 1,17 | 0,46 |
| | | 9 | 1,05 | 1,42 | 59,54 | 51,41 | 4,19 | 126,70 | 1,16 | 0,47 |
| | | 10 | 1,83 | 1,99 | 61,02 | 50,85 | 4,29 | 90,91 | 1,21 | 0,66 |
| | | mean value | 1,12 | 1,53 | 62,01 | 47,01 | 4,99 | 115,57 | **1,44** | **0,54** |

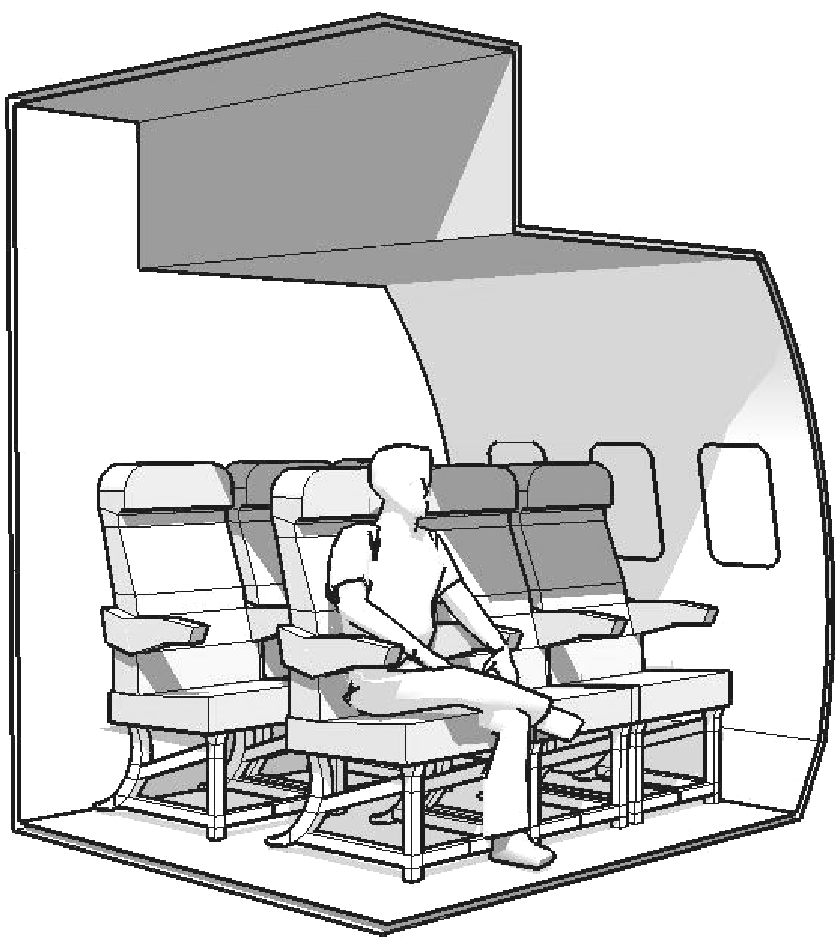
*Table C.2.13. Concentration results for combined ventilation (MV+PV), seat strap both parts*

## C.2.14. Seat stap, both parts, DV+PV

| Concentration results for DV+PV both parts | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Supply airflow from upper nozzle | Supply airflow from PV | No. | Return air nozzle | Supply PV diffuser $C_{PV}$ | Exhaust pipe $C_R$ | Monkey's nose $C_{exp,PV}$ | Laboratory $C_{lab}$ | 170cm above the floor | Ventilation index for system $\varepsilon_{exp,system}$ | Air quality index $\varepsilon_{oz}$ |
| [l/s] | [l/s] | [-] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [ppm] | [-] | [-] |
| 5 | 15 | 1 | 57,32 | 6,77 | 49,41 | 24,72 | 5,94 | 25,15 | 2,00 | 1,96 |
| | | 2 | 40,52 | 5,20 | 44,20 | 51,76 | 6,85 | 22,96 | 0,85 | 1,93 |
| | | 3 | 55,66 | 4,46 | 44,85 | 29,79 | 6,14 | 24,64 | 1,51 | 1,82 |
| | | 4 | 45,44 | 9,89 | 49,58 | 59,29 | 6,32 | 26,23 | 0,84 | 1,89 |
| | | 5 | 52,90 | 9,01 | 46,84 | 48,53 | 6,59 | 25,38 | 0,97 | 1,85 |
| | | 6 | 54,13 | 6,23 | 46,25 | 44,00 | 6,79 | 21,81 | 1,05 | 2,12 |
| | | 7 | 57,14 | 4,59 | 49,34 | 38,60 | 5,97 | 23,06 | 1,28 | 2,14 |
| | | 8 | 50,39 | 4,16 | 46,95 | 50,31 | 7,46 | 23,63 | 0,93 | 1,99 |
| | | 9 | 55,78 | 8,03 | 48,25 | 32,37 | 6,02 | 23,71 | 1,49 | 2,04 |
| | | 10 | 41,60 | 5,06 | 47,49 | 21,65 | 5,27 | 20,58 | 2,19 | 2,31 |
| | | mean value | 51,09 | 6,34 | 47,32 | 40,10 | 6,34 | 23,72 | **1,31** | **2,00** |

*Table C.2.12. Concentration results for combined ventilation (DV+PV), seat strap both parts*

# APPENDIX D -
# CFD SIMUALTIONS



## D.1. Governing equations

To scientist, French engineer, physicist Claude Navier and Irish mathematician, physicist Sir George G. Stokes, took significant contribution to knowledge development of fluid mechanics. One of the most important equations has been named after these two 19$^{th}$-century physicists, who derived them independently.

The governing equation such as mass, momentum and energy represent mathematical statements of the conservation laws of physics of fluid flow. This equation describes the behavior of the fluid in terms of macroscopic properties (velocity, pressure, density and temperature, and their space and time derivatives). A fluid particle is considered to be the smallest possible element of fluid, and its macroscopic properties are not influenced by other molecules. [1]

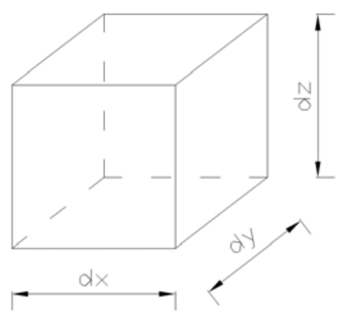



*Figure C.1.1 Fluid element for conservation laws with sides: δx δy δz*

### D.1.2. Mass conversation in three dimensions

The mass balance for the fluid element:

*Rate of increase of mass in fluid element = Net rate of flow of mass into fluid element*

$$\frac{\partial}{\partial t}\left(\rho \delta x \delta y \delta z\right) = \frac{\partial \rho}{\partial t} \delta x \delta y \delta z$$

Figure C.1.2. the equation of the unsteady, three-dimensional mass conversation or continuity equation (or continuity equation at the point in a compressible fluid). Lefts side of equations represents the rate of change in time of the density (the first term) and the net flow of mass out of the element across its boundaries (the second term). [2]

*Mass per unit volume + convective term = 0*

$$\frac{\partial \rho}{\partial t} + div(\rho u) = 0$$

*Figure C.1.2. Continuity equation.*

### D.1.2. Momentum equation in three dimensions

According to Newton's second low, the rate of change of momentum of a fluid particle equals the sum of the forces on the particle:

*Rate of increase of momentum of fluid particle = Sum of forces on fluid particle.*

It is possible to distinguish two types of forces on fluid particles:
- surface forces (pressure, viscous forces)
- body forces (gravity, centrifugal, Coriolis, electromagnetic force)

The x-component of the momentum equation consist of the rate of change of x-momentum of the fluid particle which is equal to the total force in the x-direction on the element (because of surface stresses), plus the rate of increase of x-momentum (due to sources). See Figure C.1.3.

a) $$\rho \frac{Du}{Dt} = \frac{\partial(-p+\tau_{xx})}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + S_{Mx}$$

b) $$\rho \frac{Dv}{Dt} = \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial(-p+\tau_{yy})}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + S_{My}$$

c) $$\rho \frac{Dw}{Dt} = \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial(-p+\tau_{zz})}{\partial z} + S_{Mz}$$

*Figure C.1.3. Components of the momentum equation, a) x- , b) y- , c) z-component*

The source term $S_{Mx}$ , $S_{My}$ , $S_{Mz}$ , include contributions due to body forces only. For better understanding example is provided: The body force thanks to gravity would be represented by $S_{Mx}$=0, $S_{My}$=0, $S_{Mz}$=-ρg. [2]

### D.1.3. Energy equations in three dimensions

The first law of thermodynamics states that the rate of change of energy of a fluid particle is equal to the rate of heat addition to the fluid particle plus the rate of work done on the particle:

*Rate of increase of energy of fluid particle*
*=*
*Net rate of heat added to fluid particle + Net rate of work done on fluid particle*

The net rate of heat transferred to the fluid particle (because of heat flow in x-, y-,z-direction) is given by the difference between the rate of heat input across one face, and the rate of heat loss across opposite face. The rate of work done on the fluid particle in the element by a surface force is equal to the product of the force and velocity component in the direction of the force. [2]

It is necessary to add the rate of increase of energy (due to sources) to the energy equation. See Figure C.1.4.

$$\rho\frac{DE}{Dt} = -div(pu) + \left[\begin{array}{l}\frac{\partial(u\tau_{xx})}{\partial x} + \frac{\partial(u\tau_{yx})}{\partial y} + \frac{\partial(u\tau_{zx})}{\partial z} + \frac{\partial(u\tau_{xy})}{\partial x} + \frac{\partial(u\tau_{yy})}{\partial y} \\ + \frac{\partial(u\tau_{zy})}{\partial z} + \frac{\partial(u\tau_{xz})}{\partial x} + \frac{\partial(u\tau_{yz})}{\partial y} + \frac{\partial(u\tau_{zz})}{\partial z}\end{array}\right] + div(kgradT) + S_E$$

$$E = i + \frac{1}{2}\left(u^2 + v^2 + w^2\right)$$

*Figure C.1.4. The Energy Equation (i –stand for internal energy).*

### D.1.4. Navier Stokes equations

The Navier-Stokes equations describe the motion of fluid substances such as liquids and gases. These equations establish that changes in momentum in infinitesimal volumes of fluid are simply the sum of dissipative viscous forces (similar to friction), changes in pressure, gravity, and other forces acting inside the fluid: an application of Newton's second law to fluid. [2]

This equation can be written in the most useful form the development of the finite volume method:

$$\rho\frac{Du}{Dt} = -\frac{\partial p}{\partial x} + div(\mu gradu) + S_{Mx}$$
$$\rho\frac{Dv}{Dt} = -\frac{\partial p}{\partial y} + div(\mu gradv) + S_{My}$$
$$\rho\frac{Dw}{Dt} = -\frac{\partial p}{\partial z} + div(\mu gradw) + S_{Mz}$$

*Figure C.1.5. Navier-Stokes equation.*

Using the Newtonian model for viscous stresses in the internal energy equation it is possible to obtain this version:

$$\rho \frac{Di}{Dt} = -pdivu + div(kgradT) + \Phi + S_i$$

## *D.2. Computational Fluid Dynamics program*

### D.2.1. Overview

To conduct Computational Fluid Dynamics simulations we are using FLOVENT (v.6.1 and v.7.2) program. CFD is the analysis of systems involving fluid flow, heat transfer and associated phenomena such as radiation by means of computer-based simulation. CFD is a computer-predictive tool that enables the analysis of the air flow processes. It helps to improve and optimize the design of existing or new ventilation or heating systems. Simulations in CFD are getting more and more common in many branches of industry, civil engineering, research institutes, and universities around the world. Beside Flovent there are few other tools for conducting those simulations. [1]

### D.2.2. The Solution Method

It is not possible to find general analytical solution for the conservation equations and their associated boundary conditions. There are particular solutions for simple models, but the problem increase in case of vest majority practical interests. Than equations can only be solved by means of numerical integration (like in CFD).

In FLOENT user has to generate grid, make sub-division of the domain into a number of smaller, non-overlapping sub-domains. The accuracy of solutions is governed by the number of cells in the grid. It means that the larger number of cells the better the solution accuracy. Figure D.2.1. show the layout and a velocities for a grid of 244 cells.

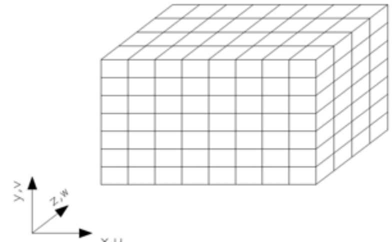



*Figure D.2.1. Layout of 244 cells grid (8x4x7)*

Each discretization results in a set of algebraic equations, relates the value of a variable in a cell to its value in the nearest-neighbour cells.
For example, letting T donate the temperature, the algebraic equation connecting T in a cell to its value in its six neighbouring cells ($T_1$, $T_2$, $T_3$, $T_4$, $T_5$, $T_6$) and its value at the old time step ($T_0$) is written:

$$T = \frac{(C_0T_0 + C_1T_1 + C_2T_2 + C_3T_3 + C_4T_4 + C_5T_5 + C_6T_6 + S)}{C_0 + C_1 + C_2 + C_3 + C_4 + C_5 + C_6}$$

$C_i$ is the coefficient that links the in-cell value to each of its neighbouring-cell values. The terms that represent the influence of the boundary condition (it there are any, like heat source) are donated with S.

The number of algebraic equations need to be solved is always the same as number of cells in total that the integration domain consist of. For example, for each of the filed variables T, u, v, w, p there are 5n equation to solve. If grid consist of 20000 cells it means that 5x20000=100000 equations that need solving. However, if KE turbulence model is used, or if concentration has been taken into consideration, the number of equations will be larger.

It might be misleading that expressed in the above form equations appear to be linear, but in fact, they are not (functions of T, u, v, w and p are coefficient themselves). In each outer iteration the coefficients are calculated only once, and than consider as a constant. The resulting algebraic equations are solved by means of inner iteration. [1], [2], [3]

## *D.3. The Turbulence Model Specification*

A turbulence model is nothing else than a computational procedure to close the system of mean flow equations so the different variety of flow can be calculated. There are few turbulent models that CFD can cope with: classical (based on Reynolds equations) and large eddy simulations (based on space-filtered equations). In this chapter three models are analysed: Capped LVEL, LVEL Algebraic, LVEL k-epsilon model. [2]

### D.3.1. Algebraic LVEL

In This Turbulence Model there is no need to define any velocity or length scale. The cell velocity stands for velocity scale. Cell turbulent viscosity is calculated from previously mentioned velocity (and length scale) in conjunctions with classical boundary layer wall functions. This model, unlike the algebraic model, results in a turbulent viscosity that varies from cell-to-cell in the bulk flow. LVEL Algebraic is identical to Capped LVEL, except the calculated turbulent viscosity field is not capped, so there are no data entry options. This is not normally the appropriate model to use for open spaces as modelled for the built environment. [4]

### D.3.2. Capped LVEL

A significant turbulence contributor comes from air flow over solid surfaces. The LVEL model calculates the turbulent viscosity to account for this. It computes a length scale, varying from point to point, based on objects in the system. This scale, together with the locally computed velocity, is used to compute a turbulent viscosity.

The LVEL model is particularly appropriate for cases that are cluttered with objects and has the advantage that there are no user settings. The disadvantage is that it may produce artificially high turbulent viscosities away from surfaces particularly in large open spaces.

When Capped LVEL is chosen, the program limits the turbulent viscosity to a calculated maximum by multiplying the molecular (or laminar) viscosity of the fluid (set in the Fluid Property dialog) by the value you enter in the Multiplier field. This viscosity is used as a cap to prevent viscosities becoming unrealistically high in open spaces where the object surface in reality would have no effect, and the LVEL model for the wall is no longer appropriate.

This is therefore defined as follows:

*Turbulent viscosity = multiplier x laminar viscosity*

The macroscopic mixing of heat energy is presumed to be controlled by the general turbulent mixing process, so that the program calculates the turbulent conductivity from the following expression:

*Turbulent conductivity = turbulent viscosity x specific heat / 0.9*

where 0.9 is the base default value for the turbulent Prandtl number.

The advantage of the Capped LVEL model is that it represents the effect of additional mixing caused by turbulence and the local effects of surfaces, without any additional transport equations. However, it does not represent any of the variation in the

turbulence that occurs in open space due to free jets or buoyant plumes creating velocity shear. This mixing is only represented by the average uniform value.
For detailed calculations, or where the turbulence is dominated by velocity shears, such as those occurring at the boundaries of free jets, the Revised KE Model should be used. [4]

### D.3.3. LVEL k-ε

Near the wall, the effect of turbulence is calculated by the LVEL model described in Capped LVEL, but this is blended with the k-ε approach. The k-ε approach calculates the turbulent viscosity for the fluid cells not immediately adjacent to solid surfaces as a function of two field variables, viz. the kinetic energy of the turbulence (k) and its rate of dissipation - ε. These two field variables are determined by the solution of two additional differential equations which these variables satisfy.

This allows, more properly, for the turbulent variations in effective viscosity caused by velocity shears from free jets etc. in open spaces.

At flow boundaries, turbulent kinetic energy and turbulent dissipation are convected in by the flow. The levels of these values are set by the user in the Ambient Attribute Dialog or in the appropriate flow dialog. If left at the default of zero, an estimate is made based on the flow rate calculated from the average inflow speed.

The LVEL k-ε model should be selected for all detailed/final calculations for the built environment unless the model is very cluttered with geometry with little open space or you know that the flow is laminar (not just unidirectional). [4]

#### D.3.3.1. LVEL k-ε and Startification

When the k-ε model option is chosen, then there is an option of including buoyancy generation terms by activating stratification. This option might be used only where the temperature differences in the air are large (e.g. fires) or there are large density variations from contaminants. [4]

#### D.3.3.2. LVEL k-ε Additional Solution Variables

The LVEL K-Epsilon model defines the turbulent viscosity at each point from two additional variables that characterize the local state of turbulence:

- k-ε Turb., the kinetic energy of turbulence, and
- k-ε Diss., its rate of dissipation

In the k-ε model, these two additional fields are solved at each cell thereby providing a turbulent viscosity which differs from cell to cell.

The k-ε Turb. and Diss. are calculated based on average inlet velocity values as follows:

$$kinetic\ energy\ of\ turbulence = 10^{-3} \times [velocity]^2$$

$$dissipation\ rate\ of\ turbulence = \frac{0.1643 \times [10^{-3} \times (velocity)^2]^{3/2}}{l_i}$$

where:

$$l_i = 0.1 \times (nominal\ inlet\ area)^{\frac{1}{2}}$$

These automatic boundary settings are usually suitable because the generation of turbulence within the calculation domain is normally sufficiently high to make precise settings of the inlet values inconsequential. [4]

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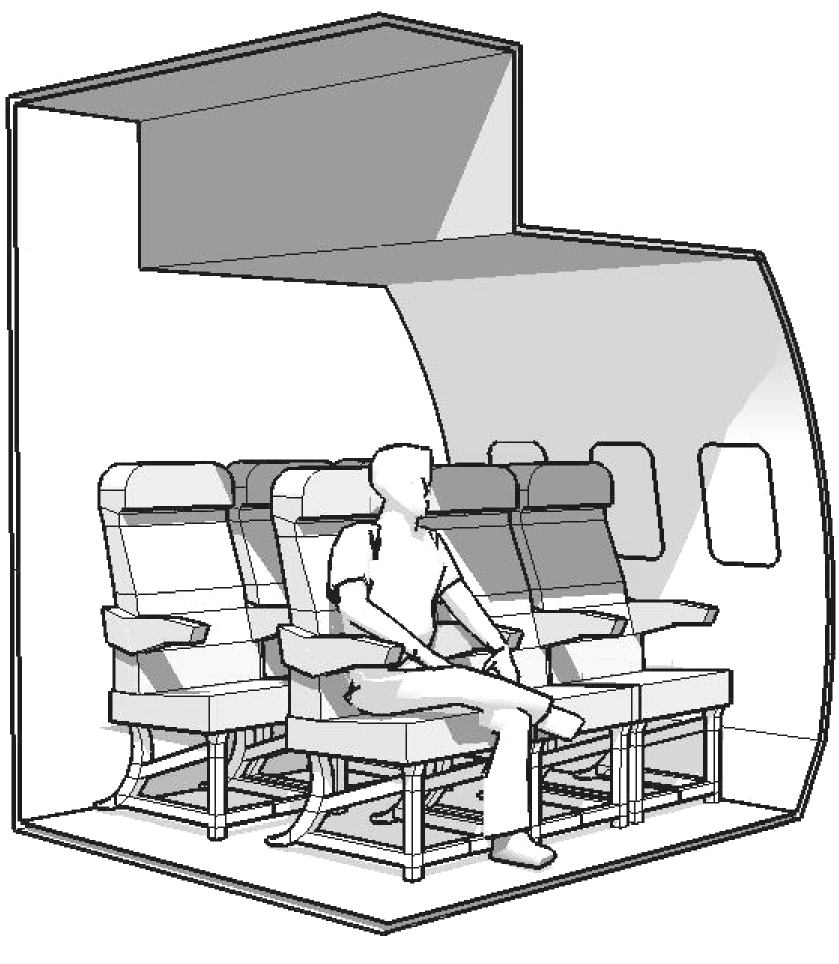
- [4] FLOVENT help file,

# POLISH SUMMARY



*"Im więcej wiesz, tym więcej pozostaje do poznania"*
*Francis Scott Fitzgerald, 'Ostatni z wielkich'*

# 1. Wstęp

Projekt „Optimalisation of Personal Ventilation In Aircrafts" („Optymalizacja Wentylacji Osobistej w Samolotach") jest kontynuacją projektu z 9tego semestru na duńskim Uniwersytecie w Aalborgu, "New Solution for Personalized Ventilations in Aircraft. Textile Ventilating Surface" („Nowe Rozwiązania Wentylacji Osobistej w Samolotach. Tekstylne Materiały Wentylacyjne") [1], którego byliśmy współautorami. Doczekał się on już publikacji podczas konferencji w Nowym Jorku i Kopenhadze [2]. Ten, któremu poświęcona jest ta praca, dotyczy optymalizacji typów i kształtów nowych rodzajów tekstylnych nawiewników osobistych, jako nowatorskiego rozwiązania wentylacji w samolotach.

Współczesny styl życia, jak i warunki pracy czy podróżowania, zmuszają ludzi do przebywania wewnątrz zatłoczonych pomieszczeń. Sprzyja to rozprzestrzenianiu się zarazków, źródeł chorób przenoszonych drogą kropelkową, przykrych zapachów, lub innych zanieczyszczeń powietrza. Z uwagi na różnorodny charakter pracy, wykonywanych czynności, sposobu przemieszczania się ludzi, czy nawet rodzaj okryć wierzchnich, ciężko jest zapewnić wszystkim odpowiednie parametry świeżego powietrza.

Coraz częstszym sposobem radzenia sobie z tym problemem jest stosowanie systemów wentylacji osobistej (PV- Personal Ventilation). System ten, wg wszelkich badań, jest najbardziej efektywnym systemem zapobiegającym przenoszeniu się chorób drogą kropelkową. Świeże powietrze dostarczane jest prosto do strefy oddychania dzięki różnym rodzajom nawiewników (panele, dysze, kratki wentylacyjne umieszczone bezpośrednio w strefie przebywania/pracy ludzi). Tego typu rozwiązania mogą mieć także swoje zastosowanie w grupowych środkach transportu, takich jak samoloty, pociągu, autobusy, lub nawet wyprzedzając badania, salach konferencyjnych, biurach typu open-space.

Problem staję się bardziej poważny gdy mamy do czynienia z recyrkulacją powietrza, co jest typowym zabiegiem w układach wentylacyjnych samolotów. Starsze modele dostarczały do kabiny 100% świeżego powietrza, podczas gdy nowoczesne tylko 50% (pozostała połowa to powietrze recylkulowane). W przypadku gdy jeden z pasażerów zacznie kichać lub kaszleć, zarazki przedostają się od razu do otoczenia i są porywane przez wywiewniki. Zastosowanie nawet najlepszych filtrów nie jest w stanie zapobiec rozprzestrzenianiu się potencjalnych źródeł chorób czy zanieczyszczeń.

Pierwszy raz świat usłyszał o tego typu zagrożeniu w 2003 roku, kiedy to 18tu pasażerów zostało zainfekowanych wirusem SARS (Severe Acute Respiratory

Syndrome - zespół ostrej ciężkiej niewydolności oddechowej) podczas lotu z Hongkongu do Pekinu. Pierwsze objawy tej choroby wykryto w 2002 roku w chińskiej prowincji Guangdong, skąd rozprzestrzeniła się na świat właśnie za sprawą lotów linii lotniczych z Hongkongu (swoistej 'bramy' łączącej Azję z Europą). Mimo że od tego zdarzenia minęło już kilka lat, to skutki widoczne są na przejściach granicznych w Hongkongu do dnia dzisiejszego. Kampania zdrowotna, maski na twarzach zarówno urzędników jak i zwykłych mieszkańców, to dość częsty widok.

Warto dodać iż nie tylko SARS może być przenoszony przez powietrze wewnątrz samolotów. Także różyczka, gruźlica, ospa wietrzna, wąglik czy grypa. Przykładem może być przypadek z 1977 roku, kiedy to samolot z 54 pasażerami na pokładzie miał 3 godzinne opóźnienie podczas lotu. W tym czasie wentylacja na pokładzie maszyny została wyłączona. W przeciągu 3 kolejnych dni 72% podróżnych owego lotu zachorowało na grypę. Powód: obecność jednego chorego na pokładzie opóźnionego samolotu.

Poza niewątpliwymi zaletami PV, system ten posiada także jedną podstawową wadę- spełnia swoją rolę tylko wtedy gdy osoba pozostaje praktycznie w bezruchu, ( w przypadku samolotów - siedząc w fotelu).

Wykonywane badania składają się z dwóch głównych części. Pierwsza polega na badaniu najlepszego kształtu i typu nawiewnika osobistego. Uwaga skupiona jest na 3 rodzajach: seat strap (nakrycie fotela z półprzepuszczalnymi dla powietrza częściami w kształcie pasów), seat cover (podobne nakrycie, z półprzepuszczalną powłoką na całej powierzchni) oraz typ naszego pomysłu -angled seat cover (wersja seat cover z częścią górną, przy głowie, zagięta z dwóch stron pod kątem 45 stopni). Te badania przeprowadzane są w modelu zwanym 'wind tunnel', symulującym pełnowymiarowym fragment kabiny samolotu Boeing 737, wyposażony w oryginalny fotel.

Druga część badań poświecona jest dobraniu odpowiedniego systemu nawiewu powietrza do kabiny, pracującego niezależnie od wentylacji osobistej. Tu badania przeprowadzane są w modelu fragmentu kabiny samolotu Boeing 737-200 w skali 1:1 (zwanym „Cabin Section"), wyposażonym w dwa rzędy siedzeń, oraz dwa manekiny. Pomiary poświęcone są czterem systemom: MV- tzw., wentylacji mieszającej, DV – wentylacji wyporowej, kombinacji MV i wentylacji osobistej (MV+PV), oraz kombinacji DV i PV. Warto zaznaczyć, że wentylacja mieszająca to system na którym opierają się współczesne samoloty pasażerskie, natomiast zastąpienie jej wentylacją wyporową jest naszym nowatorskim pomysłem.

W obu modelach używane są nowoczesne manekiny odzwierciedlające życiowe funkcje człowieka. Posiadają one możliwość regulacji poziomu oddechu, jak i, dzięki możliwości ogrzania powierzchni ich 'ciała', reagują na zmiany temperatur otoczenia (komfort termiczny). W modelu ‘wind tunnel’ wykorzystany jest manekin zwany „Comfortina” będący jedynym tego typu urządzeniem w Danii (rozdział B.5.1). Natomiast w modelu ‘cabin section’ dodatkowo użyty jest manekin zwany „Monkey” (rozdział B.5.2.). W tym przypadku Comfortina pełni rolę osoby zarażającej (źródło), natomiast „Małpa” zarażanej (cel).

Dla odróżnienia czystego powietrza od potencjalnego zanieczyszczenia, wszystkie pomiary opierają się na użyciu $N_2O$ (gaz znacznikowy).

Aby zobrazować rozkład powietrza, jak i zweryfikować wyniki otrzymane dzięki użyciu $N_2O$, przeprowadzane są symulacje dymem.

Jeden z rozdziałów poświęcony jest nowej dziedzinie komputerowego symulowania przepływów powietrza – Computational Fluid Dynamic (CFD). Za pomocą programu FloVent symulowane są wspomniane wyżej cztery przypadki systemów wentylacji. Ich wyniki stanowią ciekawe zestawienie z wynikami badań laboratoryjnych. (rozdział 8.)

Appendixy stanowią dodatkowe, pełniejsze informacje dotyczące wykonywanego projektu. Część A opisuje laboratorium w którym przeprowadzane są badania, część B poświęcona jest wszystkim urządzeniom wykorzystywanym w czasie pomiarów. W części C znaleźć można pełne tabele ze stężeniami gazu znacznikowego $N_2O$ dla wszystkich pomiarów, natomiast część D ma za zadanie przybliżyć podstawowe informacje o symulacjach CFD.

Z uwagi na nowatorskość idei, jak i wielką pomoc ze strony naszego duńskiego opiekuna, profesora Petera V. Nielsena, który jest prekursorem pomysłu oraz światowej sławy ekspertem w dziedzinie mechaniki płynów, mamy wielką nadzieję że nasz projekt będzie stanowił doskonałą podstawę do dalszych badań. Wierzymy, że przyczyni się on do polepszenia jakości powierza w samolotach, a co za tym idzie, do ochrony pasażerów przed rozprzestrzenianiem się chorób przenoszonych drogą kropelkową. Warto dodać, że projektem poważnie zainteresował się światowy potentat produkujący samoloty, firma Boeing Company z siedzibą w Seatle, USA.

## 2. PV – Podstawy wentylacji osobistej

W zależności od rodzaju ubrań, wykonywanych czynności, indywidualnych upodobań dotyczących temperatury nawiewu, ludzie różnie odczuwają komfort termiczny. Zakres preferowanej temperatury może wahać się nawet o 10°C, natomiast prędkości nawiewanego powietrza do czterech razy. To może tłumaczyć narzekania na tzw. środowisko wewnętrzne, otaczające danego człowieka. Używając PV każdy jest w stanie zoptymalizować temperaturę, prędkość czy kąt nawiewu.

Istnieje wiele rodzajów osobistych nawiewników, które mogą być stosowane w otoczeniu pracy człowieka. Przenośne panele, specjalne nakładki na monitor, pionowe jak i poziome kratki nawiewne to tylko jedne z nich (patrz rozdział 4.4.1).
Liczne badania wskazały, że stosowana osobista wentylacja może osiągać 50%-100% efektywności, co stanowi 1-2 krotnie większą wartość niż zwykła wentylacja bądź wentylacja wyporowa.

Z ekonomicznego punktu widzenia wentylacja osobista jest dużo bardziej sprawnym systemem. Mniejsza objętość dostarczanego powietrza, a także, w zależności od potrzeb, możliwość swobodnego włączania i wyłączania, prowadzi do znaczących oszczędności energii. Jest to jeden z podstawowych aspektów nowoczesnej klasyfikacji budynków LEED (The Leadership in Energy and Environmental Design, Green Building Rating System™), który ma na celu propagowanie idei zrównoważonego rozwoju w dziedzinie światowego budownictwa.

Zalety wentylacji osobistej:

- zwiększenie komfortu termicznego bez powodowania zbędnych przeciągów
- zwiększenie jakości dostarczanego powietrza (niska entalpia)
- zwiększenie ochrony przed rozprzestrzenianiem się chorób przenoszonych drogą kropelkową
- minimalne zakłócenia mikrośrodowiska przy sąsiadujących stanowiskach pracy
- łatwa kontrola
- ergonometria, oszczędność energii, niskie koszty instalacji i utrzymania.

Podczas projektowania stanowisk z wentylacją osobistą należy pamiętać aby wziąć pod uwagę następujące aspekty: unoszenie się powietrza na skutek konwekcji swobodnej wokół ciała człowieka, ruchy powietrza związane z oddychaniem, wentylacje główną czy termiczne ruchy powietrza.

## *3. Koncepcja nawiewników wentylacji osobistej*

Wszystkie z badanych nawiewników łączy jedna wspólna cecha - pozostają w bliskim kontakcie z ludzką skórą w strefie oddychania.
Prototypy zostały wyprodukowane na zlecenie przez duńską firmę KE Fibertec AS Company.

### 3.1. Seat Strap

Nawiewnik ten składa się z 3 części: górnej (za głową), środkowej (za plecami), oraz dolnej (dolna część siedzenia). Do każdej części powietrze dostarczane jest osobno, przez dwie pary otworów-dysz. Szczegółowy rysunek znajduje się w rozdziale 5.1.

Uszyty jest on z dwóch materiałów. Jeden, nieprzepuszczający powietrza, znajduję się na spodniej części prototypu, oraz w pasie na całej długości w miejscu zakrytym przez siedzącego pasażera. Drugi materiał to specjalna tkanina, półprzepuszczalna. To właśnie przez nią następuje dozowanie świeżego powietrza. Użyty jest on po obu stronach wierzchniej części Seat Strap'u.

Nawiewnik zajmuje praktycznie całą powierzchnie siedzenia, i docelowo byłby integralną częścią fotela. W badaniach używana jest jednak tylko część górna.

### 3.2. Seat Cover

Nawiewnik ten ma dokładnie taki sam kształt i wielkość co opisywany powyżej. Jedyna różnica polega na tym, że część przepuszczalna pokrywa całą wierzchnią część (także część przykrytą przez siedzącego pasażera).

### 3.3. Angled Seat Cover

Wygląd i wymiary tego nawiewnika opisują rysunki i zdjęcia w rozdziale 5.3. Kształt Angled Seat Cover został specjalnie zaprojektowany na potrzeby doświadczeń. Badania wykazały większą efektywność, gdy górna część, znajdująca się pod głową, odgięta jest po obu stronach twarzy pod kątem 45°.

## *4. Przeprowadzane pomiary*

Wszystkie pomiary przeprowadzane są w tym samym czasie, równolegle, co eliminuje błędy związane z potencjalnymi zmianami parametrów środowiska wewnętrznego.

### 4.1. Gaz znacznikowy $N_2O$

Aby określić efektywność badanych systemów konieczne jest rozróżnienie powietrza czystego od 'zanieczyszczonego' (w warunkach laboratoryjnych). Do tego celu używany jest tzw. gazu rozśmieszający.

Używany analizator gazu jest w stanie mierzyć stężenie tylko 6ciu próbek w jednej serii pomiarowej. Dla potrzeb pomiarów, podczas jednej serii na każdą próbkę przypada 60 sekund analizy mieszanki. Każda seria powtarzana jest 5 razy w przypadku „Wind Tunnel'u" oraz 10 razy podczas badań w „Cabin Section".

Analizator Multipoint Sammler and Dozer type 130 podłączony jest do komputera PC, który, uzyskując dane z Tracer Gas Monitor System, obrabia informacje prezentując je w formie tabel i wykresów.

Dokładną lokalizacje tub przesyłających próbki $N_2O$ do analizatora, w poszczególnych modelach pokazują schematy w rozdziałach 6.1.2 oraz 6.1.3.
Sposób liczenia efektywności dla poszczególnych modeli przedstawiają poniższe wzory:

$$\varepsilon_{PV} = \frac{c_{\exp,PV} - c_{lab}}{c_{PV} - c_{lab}} \cdot 100\%$$

[wind tunel]

gdzie:
$\varepsilon_{PV}$ – efektywność PV w „wind tunnel'u" [%]
$c_{exp,PV}$ – stężenie zanieczyszczeń we wdychanym przez manekina powietrzu [ppm]
$c_{exp,lab}$ – stężenie zanieczyszczeń w laboratorium [ppm]
$c_{PV}$ – stężenie zanieczyszczeń w powietrzu dostarczanym przez system PV [ppm]

W przypadku „cabin section" nie jest możliwe określenie efektywności z uwagi na zbyt małe wymiary modelu, przy dużym wpływie systemu PV na dystrybucje powietrza z systemu głownego. Dlatego użyty jest index wentylacji osobistej:

$$\varepsilon_{\exp,system} = \frac{c_R - c_0}{c_{\exp,PV} - c_0} \cdot 100\%$$

[cabin section]

gdzie:
$\varepsilon_{exp,system}$ – index wentylacji osobistej oraz głównego systemu [%]
$c_R$ – stężenie zanieczyszczeń w przewodach wywiewnych [ppm]
$c_0$ – stężenie zanieczyszczeń w przewodach nawiewnych [ppm]
$c_{exp,PV}$ – stężenie zanieczyszczeń we wdychanym przez manekina (Monkey) powietrzu [ppm]

Aby zobrazować ile razy wdychane przez manekin powietrze jest czystsze od otaczającego, definiujemy index wentylacji:

$$\varepsilon_p = \frac{c_R - c_0}{c_{\exp} - c_0}$$ [-] [cabin section]

gdzie:
$\varepsilon_p$ – index wentylacji [-]
$c_R$ – stężenie zanieczyszczeń w przewodach wywiewnych [ppm]
$c_0$ – stężenie zanieczyszczeń w przewodach nawiewnych [ppm]
$c_{exp}$ – stężenie zanieczyszczeń we wdychanym przez manekina powietrzu [ppm]

Dodatkowo określony jest index jakości powietrza:

$$\varepsilon_{oz} = \frac{c_R - c_0}{c_{oz} - c_0}$$ [-] [cabin section]

gdzie:
εoz – index jakości powietrza [-]
$c_R$ – stężenie zanieczyszczeń w przewodach wywiewnych [ppm]
$c_0$ – stężenie zanieczyszczeń w przewodach nawiewnych [ppm]
$c_{oz}$ – stężenie zanieczyszczeń w strefie przebywania ludzi (w korytarzu na wysokości głowy stewardessy) [ppm]

## 4.2. Prędkość przepływu powietrza

Pomiary prędkości wewnątrz modeli są ważnym elementem badań. Aby człowiek nie odczuwał przeciągu ważne jest aby prędkość nie przekraczała 0,2 m/s. Anemometr (firmy Danatec), służący do precyzyjnego określania prędkości przepływu powietrza, umieszczony jest 60cm przed twarzą Comfortiny (‘wind tunel’) oraz 4 cm poniżej luków bagażowych (tu uzyskana jest największa prędkość przepływu powietrza) w przypadku ‘cabin section’. Schematy w rozdziale głównym 6.2. obrazują rozmieszczenie anemometrów w poszczególnych modelach, jak i rozkłady prędkości.

## 4.3. Temperatura

Do pomiarów temperatury używane są termokable typu K. Cykl pomiaru trwa tyle samo co cykl pomiaru gazy $N_2O$. Komputer PC zbiera wszystkie dane z analizera i prezentuje wartości w postaci tabel i wykresów. Schematy w Rozdziale 6.3. pokazują układy rozmieszczenia termokabli w poszczególnych modelach.

### 4.4. Symulacje z wykorzystaniem dymu

Aby zwizualizować poruszanie się cząsteczek wydychanego powietrza („cabin section”), jak i zweryfikować w sposób empiryczny rezultaty uzyskane przy użyciu $N_2O$, przeprowadzone są symulacje dymem. W obu modelach dym dodawany jest do systemu PV, aby można było śledzić dystrybucje świeżego powietrza.

## *5. Otrzymane wyniki*

### 5.1. Wind Tunnel

#### 5.1.1. Problemy powstałe podczas pomiarów

Podczas badań w wind tunelu zauważonych jest kilka nieprawidłowości. W przypadku małych prędkości przepływu powietrza wewnątrz tunelu, model zachowuje się jak małe pomieszczenie. $N_2O$ wypływające z wentylacji osobistej wypełnia całą objętość modelu, zwłaszcza w przypadku dużych przepływów z systemu PV. Aby bardziej zbadać problem, czujniki stężenia gazu umieszczone są 1,5 m nad poziomem podłogi w pobliżu półprzepuszczalnej ściany (będącej wlotem powietrza do wind tunelu). Często w przypadku dużych przepływów za wentylacji osobistej a małej prędkości powietrza wewnątrz modelu, wentylator wyciągowy nie jest w stanie wyprowadzić całej objętości powietrza kanałami wywiewnymi, co powoduje cofanie się powietrza z gazem znacznikowym. Taki ruch mieszanki wpływa na brak stabilności w przepływach powietrza w całym wind tunelu. W takich przypadkach nie jest możliwe prawidłowe określenie efektywności działającego systemu.

#### 5.1.2. Seat strap, górna część, fotel w pozycji 0°

W tej części badań fotel ustawiony jest pod kątem 0° w stosunku do przepływu powietrza w modelu a górna część seat strap’u użyta jest jako nawiewnik osobisty.

Tabela i wykres w rozdziale głównym 7.1.2. przedstawiają otrzymane wyniki dla dwóch różnych prędkości w tunelu. Jednakże żadne z rezultatów pomiarów nie wydają się być prawdziwe, z uwagi na bardzo niską efektywność (zbyt niską w porównaniu do rezultatów otrzymanych podczas badań w zeszłym semestrze). Jednym z powodów mogą być problemy opisanych w powyższym rozdziale. [1]

### 5.1.3. Seat cover, górna część, fotel w pozycji 0°

W tym przypadku fotel ustawiony jest również pod kątem 0° w stosunku do przepływu powietrza w modelu a górna część seat cover'u użyta jest jako nawiewnik osobisty.

Tabela i wykres w rozdziale głównym 7.1.3. przedstawiają otrzymane wyniki dla trzech różnych prędkości w tunelu. Podobnie, z uwagi na problemy opisane powyżej, wyniki dwóch serii nie mogą być wzięte pod uwagę. Dla pozostałego przepływu otrzymana efektywność ma bardzo niską wartość (tylko 52%).

### 5.1.4. Seat strap, górna część podgięta do 45 °, fotel w pozycji 180°

Aby zoptymalizować wypływ powietrza z nawiewnika, górna część seat strap'u zostaje podgięta pod kątem 45° po bokach głowy. Wg wyników z projektu z zeszłego semestru, ustawienie fotela w pozycji 180° w stosunku do przepływu powietrza w modelu zapewnia najlepsze rezultaty. [1]

Tabela i wykres w rozdziale głównym 7.1.4. przedstawiają otrzymane wyniki dla dwóch różnych prędkości w tunelu. Aby móc odnieść się do wyników w przypadku poprzednich ustawień, obecna konfiguracja testowana jest dla takich samych przepływów powietrza. Jednakże z powodu barku stabilności prędkości, jak i problemów opisywanych w rozdziale poprzedzającym wyniki, rezultaty dla 0,03 m/s nie mogą zostać wzięte pod uwagę. Natomiast dla 0,12 m/s osiągana efektywność waha się na poziomie 94%.

Wyniki dla podgięcia nawiewnika pod kątem 45° mają bezpośredni wpływ na stworzenie angled seat cover, opisanego w rozdziale głównym 5.3.

### 5.1.5. Seat strap, środkowa oraz górna część podgięta do 45 °, fotel w pozycji 180°

W przypadku tej konfiguracji użyte są dwie części seat strap'u, środkowa oraz górna podgięta pod kątem 45° z obu stron głowy. Fotel ustawiony jest w pozycji 180° w stosunku do przepływu powietrza w modelu (powietrze wieje w tył fotela).

Tabela i wykres w rozdziale 7.1.5. opisują otrzymane wyniki dla dwóch różnych prędkości w tunelu. Z powodów opisanych na początku rozdziału jedne z wyników nie mogą zostać wzięte pod uwagę. Efektywność dla prędkości 0,1 m/s osiąga realne wartości, ale satysfakcjonujące są tylko w przypadku przepływów z wentylacji osobistej, większej niż 14 l/s. Powietrze dostarczane do środkowej części nawiewnika jest porywane przez przeciąg w modelu, zanim dotrze do strefy oddychania pasażera.

Z porównania wyników otrzymanych w tym przypadku, jak i w przypadku poprzedzającym, można wnioskować że efektywności przy użyciu dwóch części nawiewnika są gorsze niż przy użyciu tylko górnej. Spowodowane to może być faktem, ze w obu przypadkach powietrze dostarczane jest przez 4 przewody. Przy użyciu dwóch części 2 przewody zasilające przypadają na jedną część, natomiast przy użyciu tylko górnej części, powietrze dostarczane jest przez wszystkie przewody. Więcej powietrza przypada zatem na część znajdującą się pod głową, w bezpośrednim kontakcie ze strefą oddychania.

### 5.1.6. Seat cover, górna część podgięta do 45 °, fotel w pozycji 180°

W tej części badań użyta jest tylko górna część seat Doveru, również podgięta o 45° z obu stron głowy. Fotel ustawiony jest w pozycji 180 względem przepływu powietrza w modelu.

Tabela i wykres w rozdziale 7.1.6. przedstawiają otrzymane wyniki dla dwóch różnych prędkości w tunelu. Ponownie wyniki otrzymane dla jednej z nich nie mogą być wzięte pod uwagę. Poza problemami powtarzającymi się każdym przypadku, uzyskane efektywności są bardzo niskie. W przypadku prędkości w tunelu równej 0,12 m/s efektywność sięga 63%, ale da wypływów z PV powyżej 10 l/s pojawiają się opisywane wcześniej problemy. Aby lepiej zobrazować dany przypadek szczegółowe rezultaty stężęń zostały zawarte w Appendix'ie C.
Zostało przewidziane, że efektywność górnej części seat cover'u osiąga dużo większe wartośći. Jednakże potwierdzenie tej tezy oraz odniesienie jej do efektywności seat strap'a, wymaga kolejnych badań w przyszłości. Z punktu widzenia komfortu termicznego, seat strap powoduje mniejsze uczycie przeciągu niż seat cover.

### 5.1.7. Seat cover, środkowa oraz górna część podgięta do 45 °, fotel w pozycji 180°

Te ustawienie nawiązuje do identycznej konfiguracji ceat strap'u. Również dwie części nawiewnika są podłączone do systemu, przy identycznym ustawieniu fotela.

Tabela i wykres w rozdziale 7.1.7. prezentują wyniki otrzymane dla dwóch różnych prędkości w tunelu. Podobnie wyniki otrzymane dla jednej z nich nie mogą być wzięte pod uwagę, mimo iż uzyskane efektywności są dość wysokie. Natomiast dla drugiej prędkości efektywność sięga tylko 40%, a więc jest mało satysfakcjonująca.

## 5.2. Cabin Section

### 5.2.1. Wentylacja mieszająca MV

Podczas tych badań powietrze dostarczane jest górnymi dyszami, natomiast usuwane za pomocą dolnego wywiewu. Wydech jednego za manekinów stanowi zanieczyszczenie powietrza.
Dokładne zestawienia tabelaryczne oraz wykresy, dla badań przeprowadzanych w tym systemie w Cabin Section, znajdują się w rozdziale 7.2.1.

TEMPERATURY

Zakładając że warunki panujące w modelu są warunkami ustalonymi, temperatura nawiewu dla różnych przepływów obliczana jest na podstawie wzorów z rozdziału 6.3.3. Jednakże są to warunki idealne, które w naszym wypadku zakłócane są przez m.in. zmiany temperatury wewnątrz jak i na zewnątrz pomieszczeń laboratoryjnych, zmiany ciśnień atmosferycznych, wpływ wiatrów na czerpnie powietrza jak i ograniczenia w sprzęcie którym dysponujemy.

Uzyskane profile temperatury są praktycznie jednakowe dla różnych przepływów powietrza, i jednocześnie są typowe dla tego typu systemu, co pozwala zauważyć ,że biorąc pod uwagę temperaturę, układ działa poprawnie. Uzyskane odchyłki mogą wynikać z zachwiania warunków ustalonych.

PRĘDKOŚCI

Wartości mierzone są 4 cm poniżej poziomu podręcznych luków bagażowych, gdzie osiągana jest największa prędkość. Mimo iż otrzymane wyniki wydają się dość wysokie, to nie zakłócają komfortu termicznego siedzących pasażerów. Powodować mogą jedynie uczucie lekkich przeciągów w korytarzu.

STĘŻENIE ZANIECZYSZCZEŃ

Zarówno index wentylacji jak i index jakości powietrza nie osiągają wymaganych przez wartości (powyżej 1, czyli sytuacji, kiedy wartość stężenia wdychanych zanieczyszczeń jest mniejsza od wartości stężenia w powietrzu usuwanym z modelu).

### 5.2.2. Wentylacja wyporowa DV

W przypadku wentylacji wyporowej powietrze dostarczane jest nawiewnikami znajdującymi się 5 cm nad podłogą, natomiast usuwane jest przez dysze pod sufitem. Szczegółowe tabele i wykresy dotyczące wyników uzyskanych w tym systemie dostępne są w rozdziale 7.2.2.

TEMPERATURY

Podobnie jak w poprzednim wypadku założono, ze warunki panujące w modelu to warunki ustalone.

Profile temperatury jednoznacznie wykazują charakter typowy dla tego typu wentylacji. Wartości rosną wraz ze wzrostem wysokości nad podłogą. Różnice w poszczególnych profilach wynikają z różnych wartości przepływów powietrza, przy czym dla mniejszych przepływów uzyskujemy mniejsze różnice temperatur.

PRĘDKOŚCI

Wartości mierzone są tuż za nawiewnikiem, 5 cm powyżej poziomu podłogi, miejscu gdzie występują największe prędkości. Na podstawie wyników stwierdzone jest, że z pewnością pasażerowie siedzący przy oknach odczuwać będą przeciągi na wysokości stóp. Sugerowane jest aby podczas przyszłych pomiarów zmienić kształty i wymiary nawiewników.

STĘŻENIE ZANIECZYSZCZEŃ

Uzyskane wyniki różnią się od wyników dla systemu MV. Dla przepływów mniejszych niż 15 l/s index wentylacji ma wartość wyższą od jedności. Natomiast dla większych przepływów nie jest on do zaakceptowania (mimo iż index jakości powietrza równy jest 1,64). Podczas przyszłych badań sugerowane jest skupienie się nad pośrednimi wartościami przepływów.

### 5.2.3. Kombinacja MV+PV

W tym systemie świeże powietrze podawane jest zarówno przez dysze znajdujące się pod sufitem, jak i nawiewniki wentylacji osobistej. W badaniach brane są pod uwagę różne stosunki powietrza dostarczanego z MV i PV. Wywiew znajduję się tuż nad poziomem podłogi.

Przyjmuje się warunki ustalone w modelu. Szczegółowe tabele i wykresy dotyczące wyników uzyskanych w tym systemie dostępne są w rozdziale 7.2.3.

TEMPERATURY

Uzyskane profile temperatury mają podobne kształty jak w przypadku samego systemu MV, jednakże różnice temperatur na poszczególnych wysokościach mogą sięgać nawet 2°C.

PRĘDKOŚCI

Z otrzymanych wartości dla różnych przepływów możemy stwierdzić że prędkości zależą głównie od ilości nawiewanego powietrza. Jednakże duże strumienie z wentylacji osobistej mogą zakłócać wypływ z dysz pod sufitem.
Warto zauważyć, że najkorzystniejsze prędkości powietrza uzyskane są dla sumy przepływów równej 15 l/s. Tabela 7.2.12. porównuje różnice prędkości dla systemów MV oraz MV+PV. Otrzymane w drugim przypadku liczby są praktycznie dwukrotnie mniejsze.

STĘŻENIE ZANIECZYSZCZEŃ

Jak można było przewidzieć, dodanie wentylacji osobistej do systemu odbije się na jakości wdychanego powietrza (w przypadku samego MV, wartości indexów są mniejsze od jedności).

Największy index wentylacji uzyskany jest dla 15 l/s ( rośnie on wraz ze wzrostem przepływu z PV). Natomiast index czystości powietrza waha się między 0,5 a 0,9 (tylko dal 5 l/s wynosi powyżej 1). Najlepszą kombinację uzyskuje się dla 3 l/s z MV oraz 12 l/s z PV. Mimo że index czystości powietrza wynosi 0,79, może on być podwyższony podczas przyszłych badań w przypadku zamontowania dodatkowych nawiewników w korytarzu.
Pamiętać należy także, że im większe strumienie z wentylacji osobistej, tym większe ryzyko odczuwania dyskomfortu termicznego u pasażerów.

### 5.2.4. Kombinacja DV+PV

System ten zakłada dostarczanie świeżego powietrza przez nawiewniki nad podłogą oraz przez wentylacje osobistą. Badane są różne stosunki dostarczanych ilości powietrza. Wywiew odbywa się przez dysze pod sufitem.

Przyjęte są warunki ustalone w modelu. Szczegółowe tabele i wykresy dotyczące wyników uzyskanych w systemie DV+PV zaprezentowane są w rozdziale 7.2.4.

TEMPERATURY

Temperatura w modelu rośnie wraz ze wzrostem wysokości nad poziomem podłogi. Różnice między wartościami skrajnymi zależą od przepływów z nawiewników, i podobnie jak w przypadku sytemu DV, wahają się między 3,45°C a 4,39°C.
PRĘDKOŚCI

Ponownie otrzymane wartości są relatywnie duże ( w najmniej korzystnym przypadku nawet do 1 m/s), co z pewnością będzie miało wpływ na komfort termiczny pasażerów siedzących przy oknach. Dlatego w przypadku przyszłych badań powinno się rozpatrywać mniejsze przepływy z DV (np. 5 l/s) oraz ulepszyć kształt i rozmiar nawiewników wyporowych.

STĘŻENIE ZANIECZYSZCZEŃ

Połączenie wentylacji wyporowej z osobista daje doskonałe rezultaty jeśli chodzi o zapobieganiu wdychania zanieczyszczonego powietrza. Index wentylacji przekracza nawet wartość 5,42. Niestety index jakości powietrza pozostawia wiele do życzenia (średnio równy jest 0,5). Podobnie jak w przypadku samego systemu DV, sugerowane jest podłączenie dodatkowych wywiewników w górnej strefie korytarza.

### 5.2.5. Podsumowanie

Na podstawie uzyskanych wyników sugerowane jest użycie kombinacji systemu MV+PV lub DV+PV. Oba systemy potrzebują przyszłych usprawnień i ulepszeń.
Zestawienie tabelaryczne 7.2.20 oraz wykres 7.2.11. w rozdziale 7.2.5. pozwala porównać wizualnie otrzymane wyniki.

Wśród przepływów 15 l/s (3 l/s z MV oraz 12 l/s z PV) index wentylacji ma wartość 1,53. Dla tego zestawienia maksymalna prędkość wynosi 0,159 m/s. Kolejną optymalną konfiguracją jest 5 l/s z MV + 10 l/s z PV.

Dla przepływów 20 l/s najlepsze wyniki otrzymuje się dla 5 l/s z DV oraz 15 l/s z PV, a także dla 7 l/s z DV i 13 l/s z PV. Ten system, mimo wysokich indexów wentylacji posiada dwa minusy: odczuwanie uczucia przeciągu na wysokości nóg pasażerów oraz, z powodu zbyt dużego przepływu powietrza z wentylacji osobistej, możliwość odczucia chłodu w okolicach szyi i karku.

Patrząc na wyniki indexów jakości powietrza można dojść do wniosku, iż konieczne są usprawnienia modelu w zakresie dodatkowych nawiewników/wywiewników w sektorze korytarza.

## 6. Symulacje z udziałem dymu

W celu wizualizacji wydychanego przez manekin powietrza, oraz śledzenia przepływu zanieczyszczonego powietrza przeprowadzane są symulacje z udziałem dymu.

Aby móc porównać system MV+PV z DV+PV ich rezultaty zestawione są ze sobą. Konfiguracja dla której osiągnięty jest najwyższy index wentylacji dla systemu MV+PV przedstawione są obok wyników dla najwyższego indexu wentylacji dla systemu DV+PV. Podobnie przedstawione są zdjęcia dla najgorszych indexów wentylacji, najlepszych oraz najgorszych indexów jakości powietrza.

Dodatkowo, dla tych samych ustawień przepływów powietrza wewnątrz modelu, dym dodawany jest do systemu wentylacji osobistej. Dzięki temu możliwe jest spojrzenie na problem dystrybucji powietrza nie tylko z punktu widzenia zanieczyszczeń, a także z pod kątem skuteczności działania nawiewników wentylacji osobistej.

## 7. Symulacje CFD

Computational Fluid Dynamics to komputerowe modele mające na celu przewidzieć m.in. ruchy powietrza, rozkład temperatur, prędkości czy przemieszczanie się zanieczyszczeń w symulowanym pomieszczeniu. Wyniki uzyskane dzięki zastosowaniu tego typu modelów opierają się na rozwiązaniu podstawowych równań mechaniki płynów (patrz rozdział D.1.)
Rozwój możliwości wykorzystania modeli CFD zwiększa się wraz z rozwojem możliwości współczesnych komputerów. Dzięki temu symulacje te nabierają znaczenia we współczesnych technikach projektowania, analizowania rozprzestrzeniana się gazów w pomieszczeniach, itp. Jednak rezultaty uzyskane dzięki zastosowaniu technik komputerowych wiążą się ściśle z umiejętnościami osób je przeprowadzających.

W rozdziale 8. przedstawiono wyniki symulacji dla badanych modelów.

## 8. Podsumowanie

Porównując wyniki badań dla różnych testowanych przypadków, można wnioskować, że:

- Wentylacja mieszająca w samolotach nie powinna być stosowana jako jedyny system wentylacji ponieważ żadne z testowanych ustawień nie zapewnia wskaźnika wentylacji wyższego niż 1.

- Wentylacja wyporowa w samolotach jako pojedynczy system jest dopuszczalna aczkolwiek zapewnia niską wartość wskaźnika wentylacji bliską 1.

- Połączenie dwóch systemów wentylacji jest dużo bardziej efektywne niż stosowanie pojedynczego systemu. Ponadto co widać na przykładzie różnicy wielkości wskaźników wentylacji dla wentylacji mieszającej i wentylacji mieszającej wspomaganej wentylacją osobistą.

- Stosowanie jedynie górnej części dowolnego testowanego nawiewnika wentylacji osobistej zapewnia najlepsze wyniki. Ponadto zasada ta nie zależy od użytego systemu głównej wentylacji (mieszającej lub wyporowej).

- Najwyższy wskaźnik wentylacji (5,42) uzyskano podczas nawiewania 5 l/s dyszami wentylacji wyporowej i 15 l/s z górnej części nawiewnika wentylacji osobistej.

- Testy dowodzą, że zwiększanie ilości powietrza nawiewanego za pomocą wentylacji osobistej zwiększa wskaźnik wentylacji, ale tym samym zmniejsza komfort cieplny.

- Dla takiej samej ilości nawiewanego powietrza, nawiewnik typu ‘seat strap’ powoduje mniejszy dyskomfort cieplny niż nawiewnik typu ‘seat cover’. Aczkolwiek użycie ‘seat covera’ nie wyklucza uzyskania zadowalającego komfortu cieplnego.

- Wyniki symulacji CFD dla wentylacji wyporowej wspomaganej wentylacją osobistą potwierdzają, że symulacje te powinny być jedynie stosowane jako narzędzie wspomagające projektowanie systemu wentylacji.

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