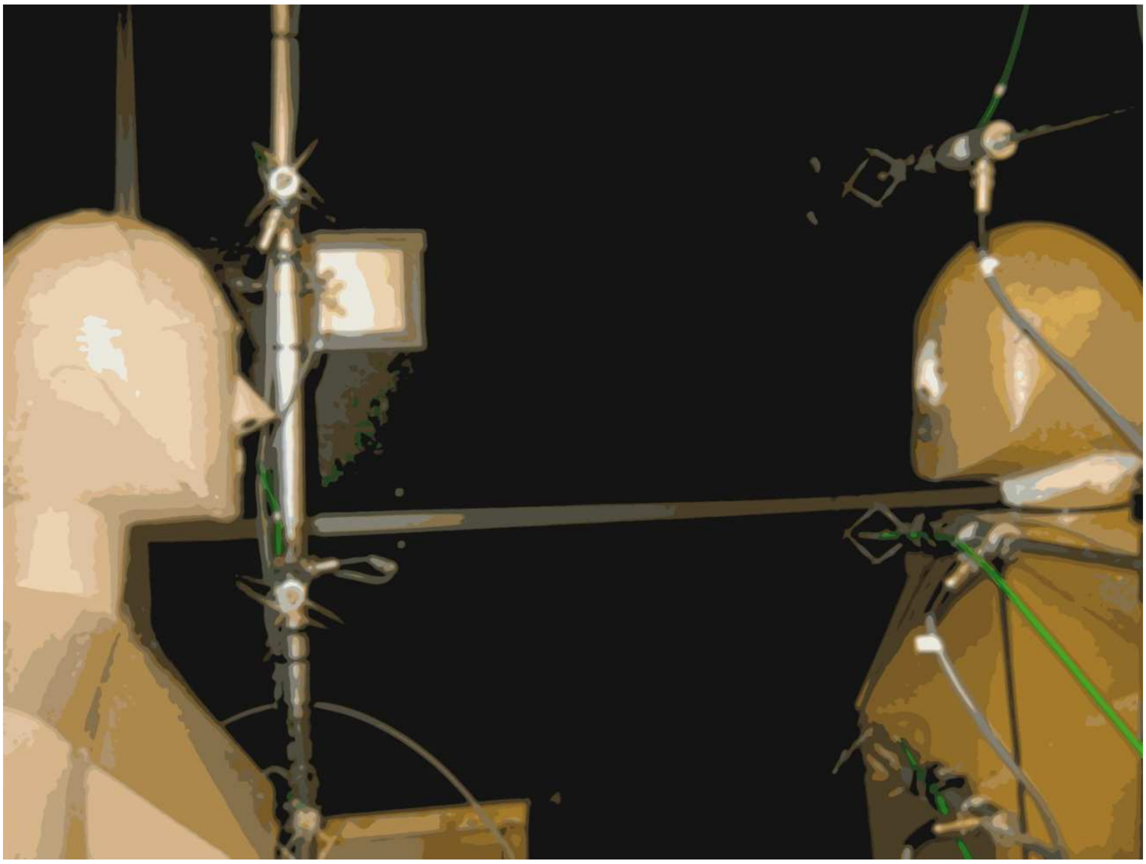
THE EXAMINATION OF COMFORT AND CROSS INFECTION IN A DISPLACEMENT VENTILATED ROOM



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Master Thesis on Indoor Environmental Engineering

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Abstract

The key case of the project is the investigation of cross infection between two persons. Furthermore two human body's properties such as a thermal plume and an exhalation are examined.
All experiments are conducted in a full scale room with dimensions 410 x 320 x 270. Two manikins with human body's functions including breathing and heat load releasing are used. Semi – circular diffuser is placed on the floor to provide displacement ventilation. Tracer gas is utilized for simulating gaseous contaminants.
Three indoor air parameters (air velocity, temperature and concentration of contaminants) are measured and distributions of them are presented.
In addition CFD simulations are performed.
Results show that a level of cross infection depends significantly on positions and distance between two people.
Furthermore thermal plume is kind of protection against cross infection.
Finally displacement ventilation is found not to be the perfect way of removing contaminants from breathing zone.

Preface

This master-thesis project on Indoor Environmental Engineering is conducted in the period 1st September 2009 till 14th 2010.

First of all the author of the project would like to thank Prof. Peter V. Nielsen for giving the opportunity of performing the project. Furthermore warm thanks for all helpful advices and useful information.

Special thanks to Ines Olmedo for great time spent together in the laboratory and fruitful cooperation.

Great thanks to Rasmus Lund Jensen for his technical support in the laboratory and useful tips.

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Piotr Grzelecki

Contents

1. Introduction

People spend 90% of their time inside. It seems that they may be worry about nothing, that they are save because they have shelter which protects them from wild and dangerous world . However that's not completely true because sometimes what's the most dangerous is invisible for our eyes. Inside they can come across microelements , such as bacterium and viruses spreading by others. Being with sick people in the same room for a long time is the easiest way to get sick .

Nowadays employers understand the problem and they want to prevent their employees from getting sick. They can provide separate room for each of them but most of them can't afford that or don't want to do it. However there is something what can provide every employer and that is appropriate ventilation system. In this case appropriate means not only the one which gives thermal comfort inside but also the one which can stop spreading contaminants from one person to another.

An objective of this project is to check the system which seems the most efficient in terms of preventing contaminants spreading – displacement ventilation.

Number of different measurements are conducted in order to get a vision of the situation.

Furthermore CFD simulations are made to get better understanding of the problem as well as to have comparison to results from measurements.

2. Background

The goal of the project is to obtain the behavior of different indoor air parameters at certain points in the room when there are people inside. The best solution would be using real people but due to huge costs of this idea it is necessary to use manikins simulating human bodies. In order to get valuable results a crucial thing is to set different manikins parameters to be in accordance with reality (real human body parameters). Those parameters are: frequency, volume and temperature of exhalation air as well as heat flux generated by manikin.

2.1 Breathing

2.1.1. Frequency of breathing

Breathing is a process consists of 3 phases : inspiration, expiration, and postexpiratory pause. [3]

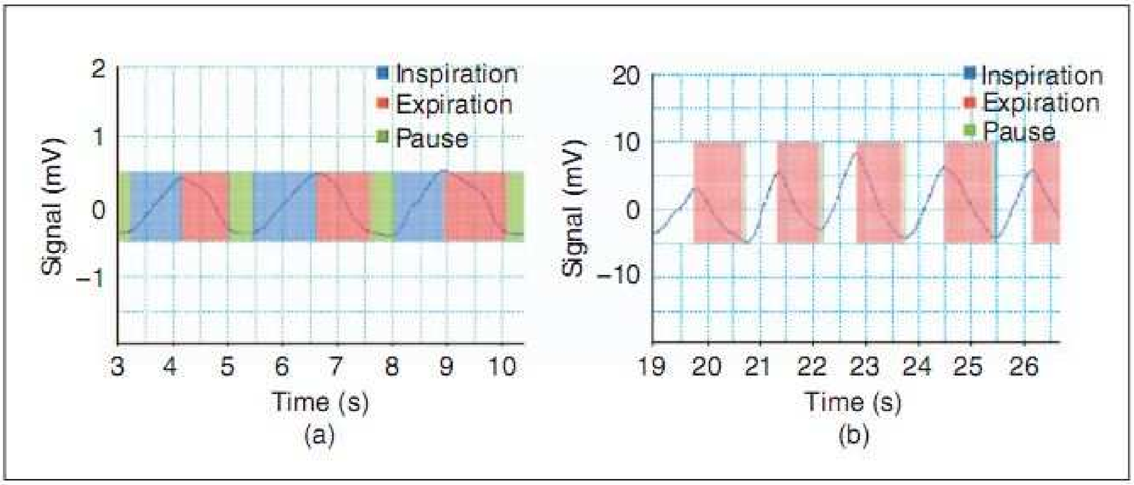


Figure 2.1 Output from piezo-respiratory belt transducer showing 3 breathing phases during quiet breathing (a) and after exercise (b) [3]

The Respiratory Belt Transducer contains a piezo-electric device that responds linearly to changes in length. It measures changes in thoracic or abdominal circumference during respiration. These measurements indicate inhalation, expiration and breathing strength .[7]

Frequency of breathing depends on activity level of the involved person. It is equal to 10-20 breaths per minute for a resting person and even 45 breaths per minute for heavy exercising one. The pulmonary ventilation rate is equal to 5-6 liters per minute for resting person and up to 20 times more for exercising one. [1]

2.1.2 Geometry of exhaled air

A human being is able to exhale in 2 ways : through a mouth or through a nose. The geometry of exhaled air jet depends on that as well as on the type of used ventilation system. As it is seen in figure 2.2 in case of exhalation through the mouth for no ventilation(a) and mixing ventilation(c) jets are similar and move upward due to temperature of the jets and strong thermal plume of the body whereas in case of displacement ventilation jet moves horizontally because of vertical temperature gradient and relatively weak plume.

Figure 2.2 Exhalation jet in case of breathing through the mouth for a)no ventilation b)displacement ventilation and c)mixing ventilation [11]

In case of exhalation through the nose exhalation jets are inclined towards the floor, what might be seen in figure 2.3

Figure 2.3 Exhalation jet in case of breathing through the nose for a) no ventilation b) displacement ventilation and c)mixing ventilation [11]

Some CFD predictions of exhalation has been made as well. Figure 2.4 show a geometry of exhaled air from mouth (a) and from nose (b). In case of exhalation through mouth one stream of air is expelled horizontally with the an axis of the jet normal to the mouth whereas in case of nose exhalation there are to streams which are expelled with angle 30° between them. An angle between them and a chest is equal to 45°.

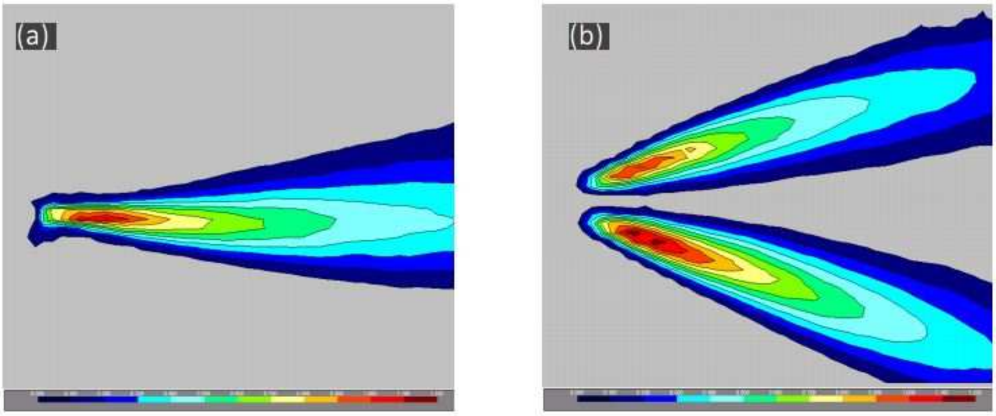


Figure 2.4 CFD prediction of exhalation jet from a mouth (a) and from a nose (b) , top view

2.1.2 Geometry of inhaled air

In case of inhalation the air comes mostly from area below level of the mouth and from front side of the body. This is the result of thermal plume energy, which captures the air and lifts it up. The amount of the air coming from different layers next to the body is seen in figure 2.5

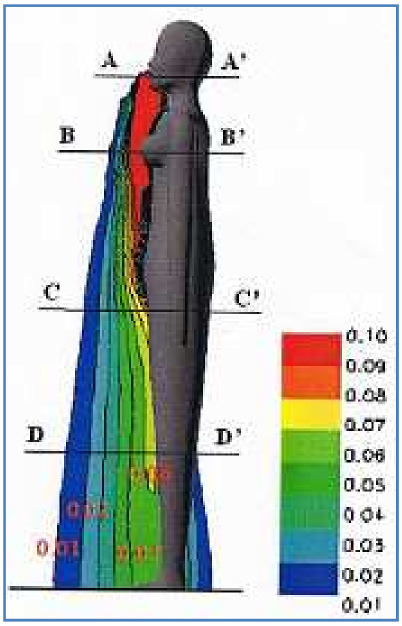


Figure 2.5 Geometry of inhaled air [10]

2.1.3 Temperature of exhaled air

Temperature of exhaled air depends on 2 factors, which are temperature of inhaling air (room temp.) and a manner of exhalation (whether it is nose or mouth).

What is seen in figure 2.6 in case of exhalation through the mouth air temperature is more stable (1°C variation) in function of ambient temperature , comparing to exhalation through the nose (5°C variation).

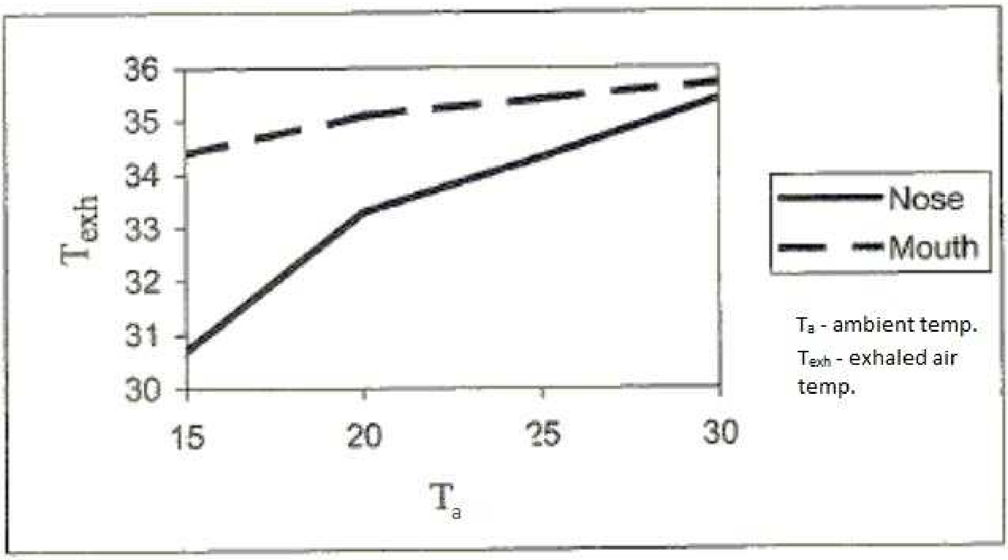


Figure 2.6 Temperature of exhaled air as a function of ambient air temperature[1]

2.2 Heat flux

In order to function in proper way human body needs to maintain temperature 37°C. Generating heat is the process which provides that. Since the ambient temperature is usually lower then 37°C then generated heat is partly lost to the surroundings. The amount of losing heat depends on ambient temperature and activity level of the person. The values of heat flux are seen in table 2.7

		Activity							
Ambient temperature		Small 0-200 W Rest and light physical labour				Medium 200-300 W Medium physical labour		High >300 W Harh physical labour	
		Rest while sitting down	Rest while standing	Office work	Clerk Student	Chemist Bank worker	Waiter	Carrier	Dancer
20	qj[W]	85	91	94	102	107	129	146	180
	wj[g/h]	41	53	71	109	129	184	243	341
21	qj[W]	82	87	92	96	100	121	138	171
	wj[g/h]	45	59	78	119	139	196	256	355
22	qj[W]	79	83	87	90	93	112	130	163
	wj[g/h]	49	64	85	120	149	208	268	368
23	qj[W]	76	79	82	84	86	104	122	154
	wj[g/h]	54	70	93	137	160	221	280	380
24	qj[W]	72	75	76	77	79	95	114	146
	wj[g/h]	60	77	101	147	171	234	292	392

Figure 2.7 Heat flux generated by human being, depending on ambient temperature and activity level, where qj is the heat flux [9]

Heat flux emited by human being consists of convective and radiative heat flux. What is seen in figure 2.8 the largest amount of heat is generated by head as well as by hands and feet.

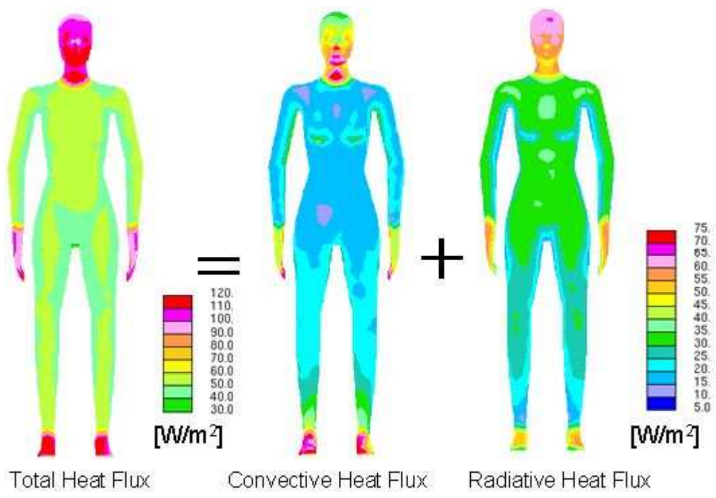


Figure 2.8 Heat flux distribution

2.3 Conclusions regarding breathing and heat flux

The literature studied above is a background, which allows to decide about manikins parameters. Following values are assumed:

- Exhalation through mouth (worse case)
- frequency of breathing equals to 15 breathing per minute
- ventilation rate equals to 11 liters per minute for source manikin and 10 liters per minute for target manikin (difference because of breathing machines original setup)
- Temperature of exhaled air equals to 34°C
- Heat flux equals to 94 W in measurements with 2 manikins and 0 W, 94 W and 120 W in measurements with one manikin in order to check the influence of thermal plume on environment around human body

2.4 Cross infection (contaminants droplets)

The reason of respiratory diseases is contact with droplets containing pathogens such as viruses, bacterium or fungi. The droplets are produced and thrown away out of mouth during breathing, speaking, coughing or sneezing. They are created in process of atomization of respiratory fluid (mucus or saliva) covering the surface of inner airways by exhaled air. If involved person is sick then respiratory fluid contains pathogens. Hence ,the droplets also contain pathogens and they are carried out together to environment. Since droplets are very small as soon as they enter to an environment a lot of different forces such as gravity and drag forces start to act on them. Therefore the behavior of droplets depends significantly on airflow in the room [4] . However if droplets are not small enough they will not stay suspended in the air for longer time. Wells (1934) showed that droplets larger than about 100 in diameter fall to the ground after 2 sec, whereas droplets smaller than 100 evaporate before falling to the ground and become 'droplet-nuclei', which may stay in the air for couple of hours or even days. [5] This way sick person can infect other person not only without physical contact but also without seeing each other.

Loads of studies concerning cross contamination have been made. It has been shown that displacement ventilation is more effective in terms of improving air quality in the office rooms compare to mixing ventilation [8]. Basing on those results it's decided to use displacement ventilation system in this project for further investigation.

2.5 Displacement ventilation

Idea of displacement ventilation bases on usage of buoyancy forces which create movement of the air inside the room. The air is usually supplied close to the floor with temperature below desired room temperature and with low velocity. The air is spread over the entire floor and then goes up after being warmed by heat sources such as people or electronic devices. Exhaust is usually located just below the ceiling. The main advantage of the system is horizontal division of the room in two parts , clean lower zone and polluted upper part. It is possible thanks to temperature gradient between lower and upper part . Desired stratification high is equal to 1.8 m for standing person and 1.1 m for sitting one but it is difficult to achieve it at normal air change rate and heat load.[6]

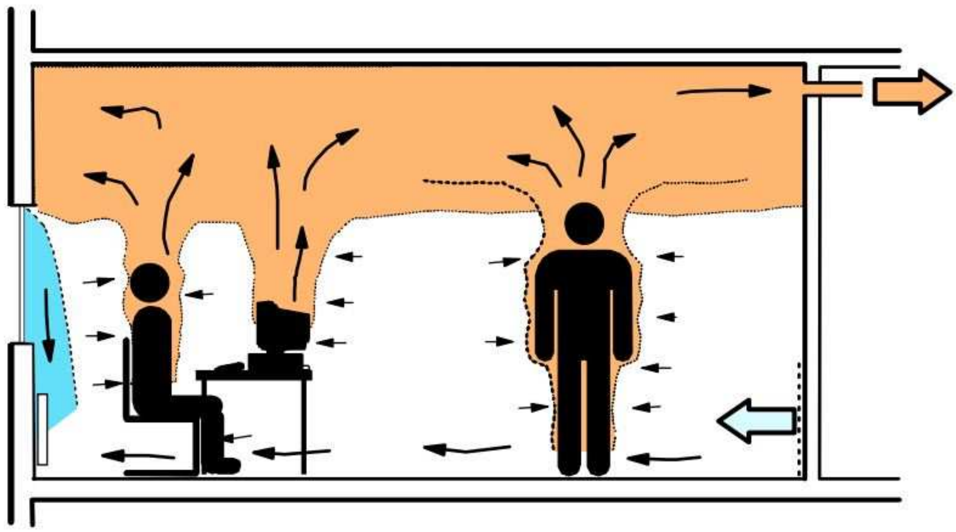


Figure 2.9 Working principle of displacement ventilation [6]

Usage of a displacement ventilation meets some limitations like:

- Displacement ventilation systems may not be appropriate when contaminants are heavier than air, or not associated with heat sources.
- When very high heat loads exist, a displacement system will require uncomfortably cold supply air. Therefore, displacement ventilation may not be appropriate in extremely warm climates.
- Displacement ventilation may not be appropriate in spaces with low ceilings.
- Displacement ventilation systems are generally poor performers when it comes to heating.
- It is necessary to reserve some area of the floor for displacement diffusers so it reduce a floor area. [6]

References:

[1] Erik Bjoern PhD Thesis, 1999, Aalborg University

[2]Mina Nishi, "Breathing of Humans and its Simulation", Friedlich-Alexander-University

Erlangen-Nuremberg, 2004

[3] Ramya Murthy, Ioannis Pavlidis, ''Noncontact Measurement of Breathing Function'' ; IEEE

Engineering in Medicine and Biology Magazine, May/June 2006

[4] Marek Brand "Review on droplets produced during human coughing and their importance for spreading of respiratory infectious diseases"

[5]J.P.Duguid "The size and the duration of air – carriage of respiratory droplets and droplet-nuclei"

[6] Peter V. Nielsen "Displacement Ventilation in non industrial premises" REHVA

[7] http://www.adinstruments.com/products/hardware/research/product/MLT1132/

[8] Bjorn and Nielsen, 2002 "Stymne at al."

[9] Systemair "Materiały pomocnicze"

[10] Murakami "Analysis and design of micro-climate around the human body with respiration by CFD"

[11] Li Liu, Yuguo Li, Peter V. Nielsen, Rasmus L. Jensen, Michal Litewnicki, Jan Zajas

Healthy Buildings, Syracuse University, 2009 "An Experimental Study of Human Exhalation during Breathing and Coughing in a Mixing Ventilated Room"

3. Setup

3.1 Full scale room.

All measurements are conducted in full scale room with dimensions 4,1 m x 3,2 m x 2,7 m. The schema and setup of equipment are given in figure 3.1 and 3.2. Equipment used in experiment is described in next chapters.

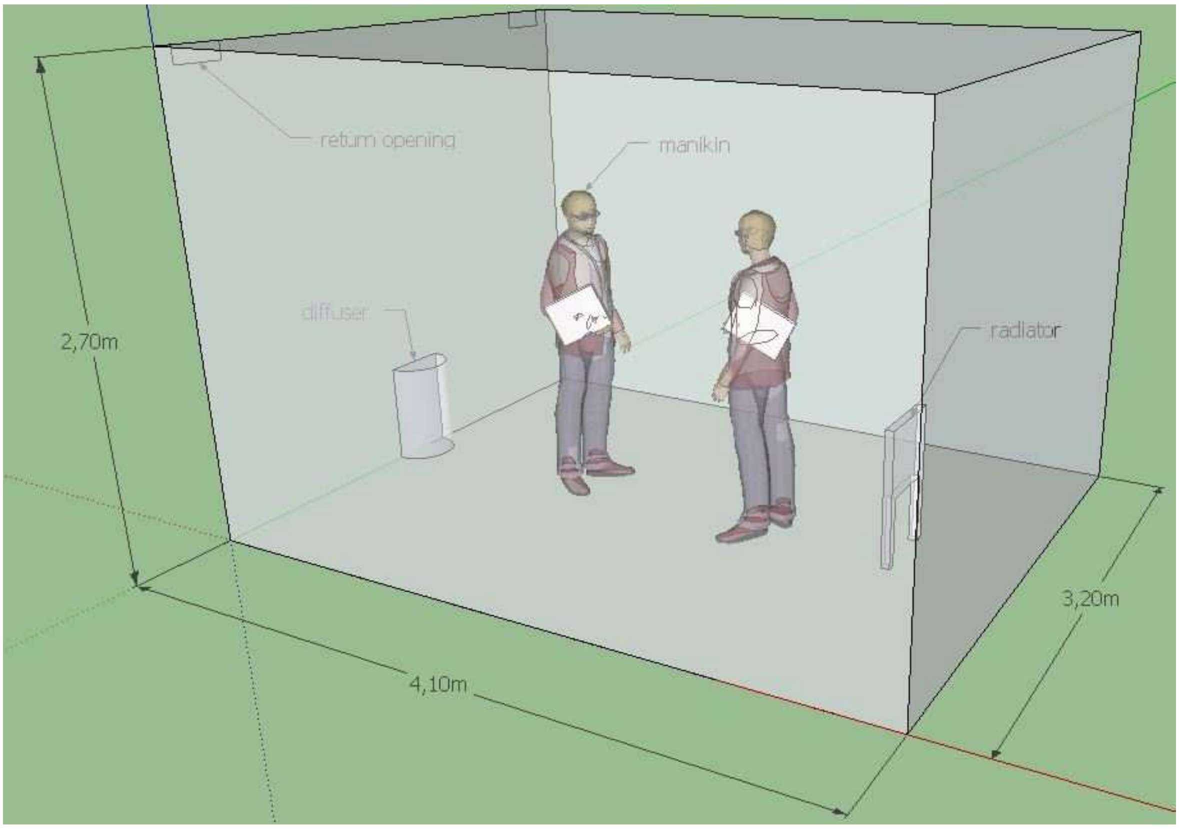


Figure 3.1 Schema of the test room

In figure 3.2 there is seen a schema of equipment setup in the room. It might be seen that air is supplied from artificial lungs to the source and target manikin's mouth, from which the air is exhaled. On the supplying tubes there are mounted small heaters to warm up the air to the temperature of 34 °C. Furthermore T-connection is made before source manikin to add a tracer gas to the exhalation air.

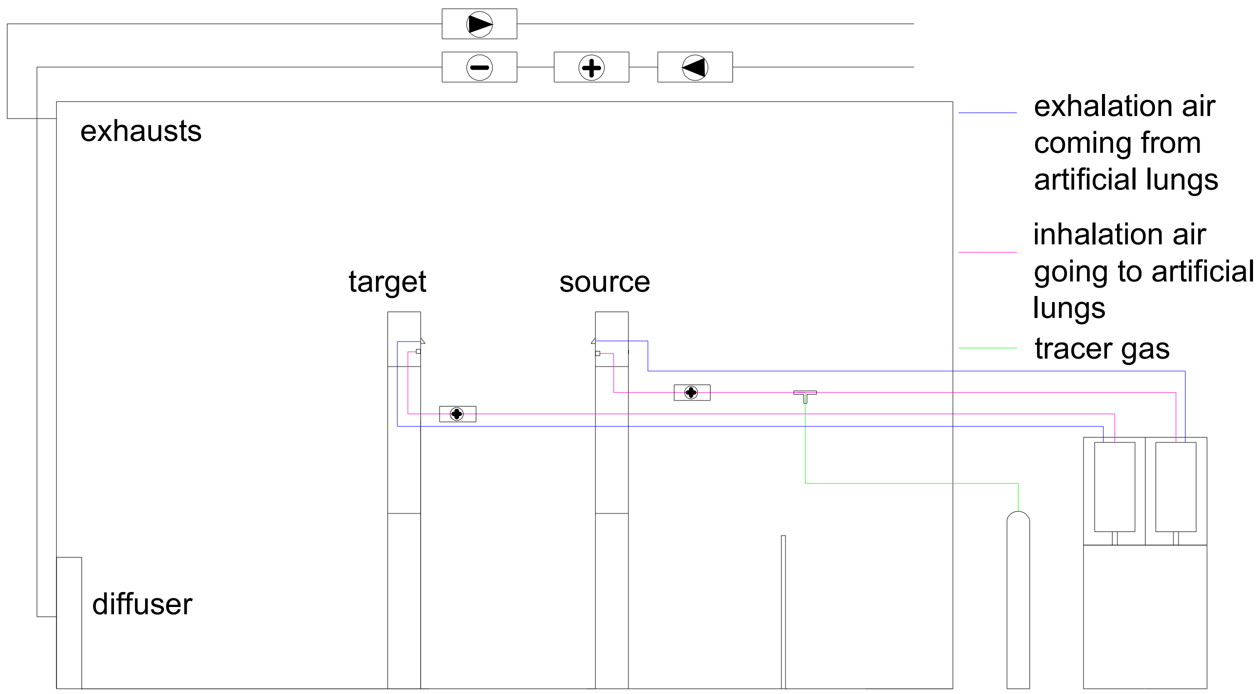


Figure 3.2 Setup of non – measuring equipment in the room

3.2 Air distribution system.

In all measurement displacement ventilation system is used. Air is supplied through semicircular diffuser located at the floor level and later on after being warmed by heat sources (in this case two manikins and radiator) it is removed through return opening. Two return openings are placed in upper corners of the same wall, at which diffuser is placed.

3.3 Semi circular diffuser.

In order to obtain displacement ventilation in the room semi – circular diffuser is used. It's placed in the middle of shorter wall touching the wall. The air is spread radially from the centre. A diameter of the diffuser is equal to 20cm and height is equal to 60 cm. A surface area is equal to 0,188 m^2. The shape of the diffuser is seen in the figure 3.2.

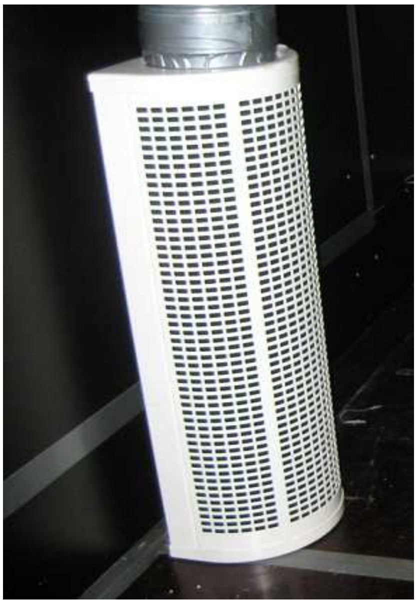


Figure 3.2 Semi-circular diffuser

In the figure 3.3 it is seen a behavior of the air coming out of the diffuser. The air falls down immediately since it has lower temperature than temperature in the room.

Figure 3.3 A smoke visualization of the air coming out of the diffuser.

3.4 Manikins and radiator

Two manikins are used to simulate real people. A shape of manikins is a bit simplified comparing to reality. However human body functions such as breathing and thermal energy producing are maintained. Thanks to artificial lungs manikins are able to simulate human breathing consisted of 2 phases: inhalation and exhalation. Manikins are set to exhale 10 l/min and 11 l/min with air temperature 34°C. The thermal energy produced by each manikin is equal to 94W. Photos of manikins are given in figure 3.5 and their dimensions in figure 3.6.

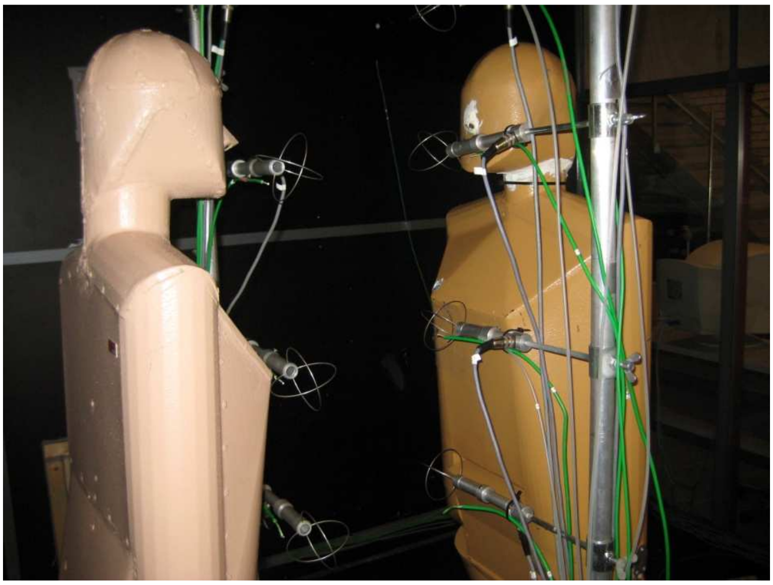


Figure 3.5 Thermal manikins

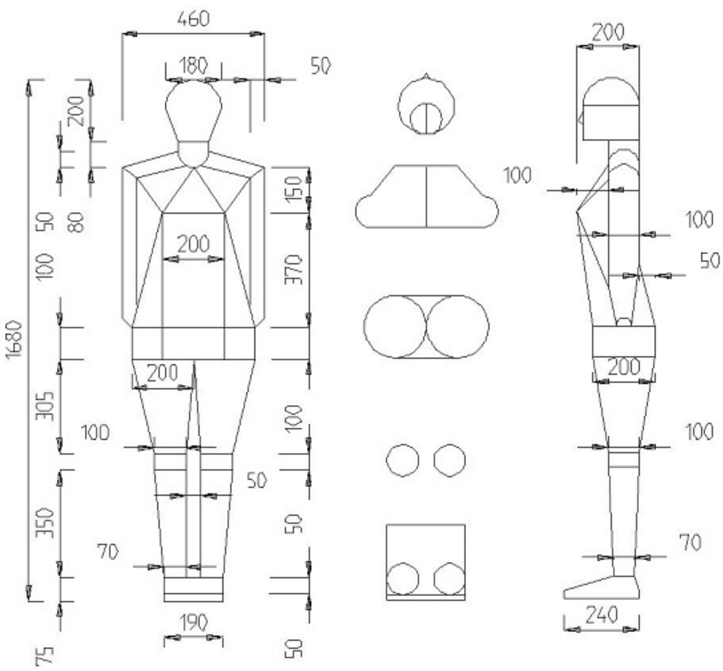


Figure 3.6 Dimensions of the manikins

One of the manikin is a source of pollutants and another one is a target. The position of both manikins is changed during measurements in order to get results showing influence of distance and position of the manikins on distribution of different indoor air parameters.

Radiator is set to produce 300W in cases with two manikins and 400 W in cases with one manikin.

3.5 Conditions

During all measurements steady state conditions are maintained. It doesn't correspond to reality where steady state conditions almost never exist. However to be able to compare different measurement results this assumption has to be made. Following conditions are used.

Energy balance

In order to avoid heat loses or heat gains energy balance has to be maintained :

$Q_{in} \approx Q_{out}$

$Q_{in} = Q_{radiator}+Q_{manikins}+Q_{breathing}$

$Q_{out} = V \cdot c_p \cdot (t_R-t_{In}) \cdot \rho$

Q_{in} – heat gains [W]

Q_{out} – heat coming out through the outlet [W]

t_R - return temperature [°C]

t_{In} - inlet temperature [°C]

V – airflow [m^3/s]

ρ – air density [kg/m^3]

c_p – specific heat capacity [J/(kg · K)]

Energy balance is calculated before every measurement.

Furthermore to avoid heat gains or heat loses through the walls average temperature in the room should be equal to laboratory temperature. The laboratory temperature is adjusted to fulfill this requirement.

$t_{aver} \approx t_{lab}$

$t_{aver} = 0,75(t_R-t_{In})+ t_{In}$

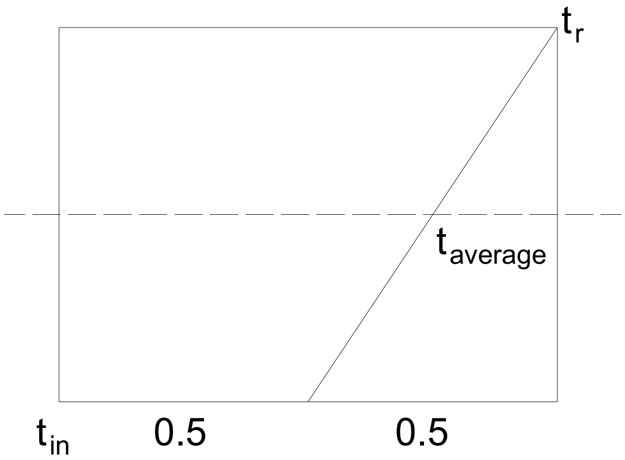


Figure 3.7 Sketch of average temperature calculations.

An example of calculations:

t_{aver} = 0,75(23-16,5)+16,5=21,6

Hence the laboratory temperature should be equal to 21,6 °C.

The investigation of fluctuations of the temperature in the lab is made. The chart in the figure 3.8 presents the results. Average temperature in the lab is equal to 21,8 °C. Therefore it might be assumed that the requirement ($t_{aver} \approx t_{lab}$) is fulfilled.

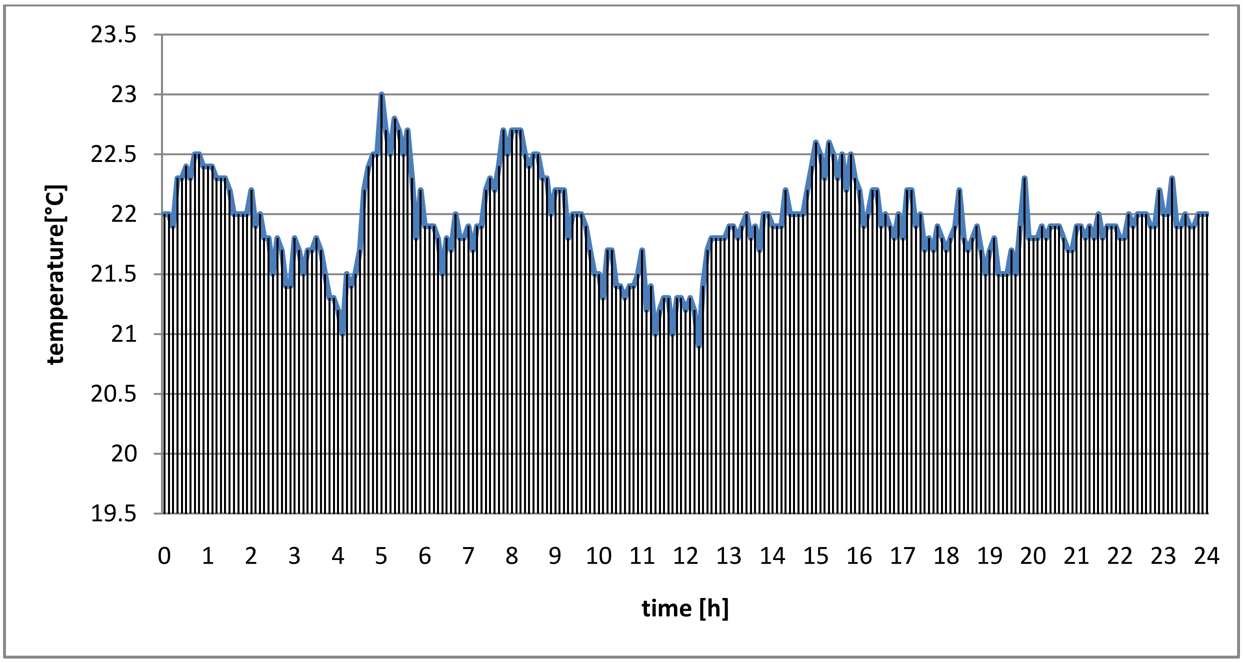


Figure 3.8 Changes of the temperature in the lab in 24h time period

Air change rate

The same air change rate equal to 5,7 h^{-1} (0,56 m^3/s) is used in all experiments. This value of air change rate provides appropriate conditions in the room.

3.6 Measured parameters and location of measuring points

Three different parameters are measured. Those are: temperature, air velocity and tracer gas concentration.

Temperature

Temperature is measured at 37 different points including temperature of the surfaces, laboratory temperature, 2 gradients of air temperature next to manikins fronts, gradient of air temperature in the corner or the room, inlet and outlet air temperatures. Furthermore the temperature of exhaled air is measured before every test to keep it at desired level (34°C). A sketch with positions of some points is given in figure 3.9.

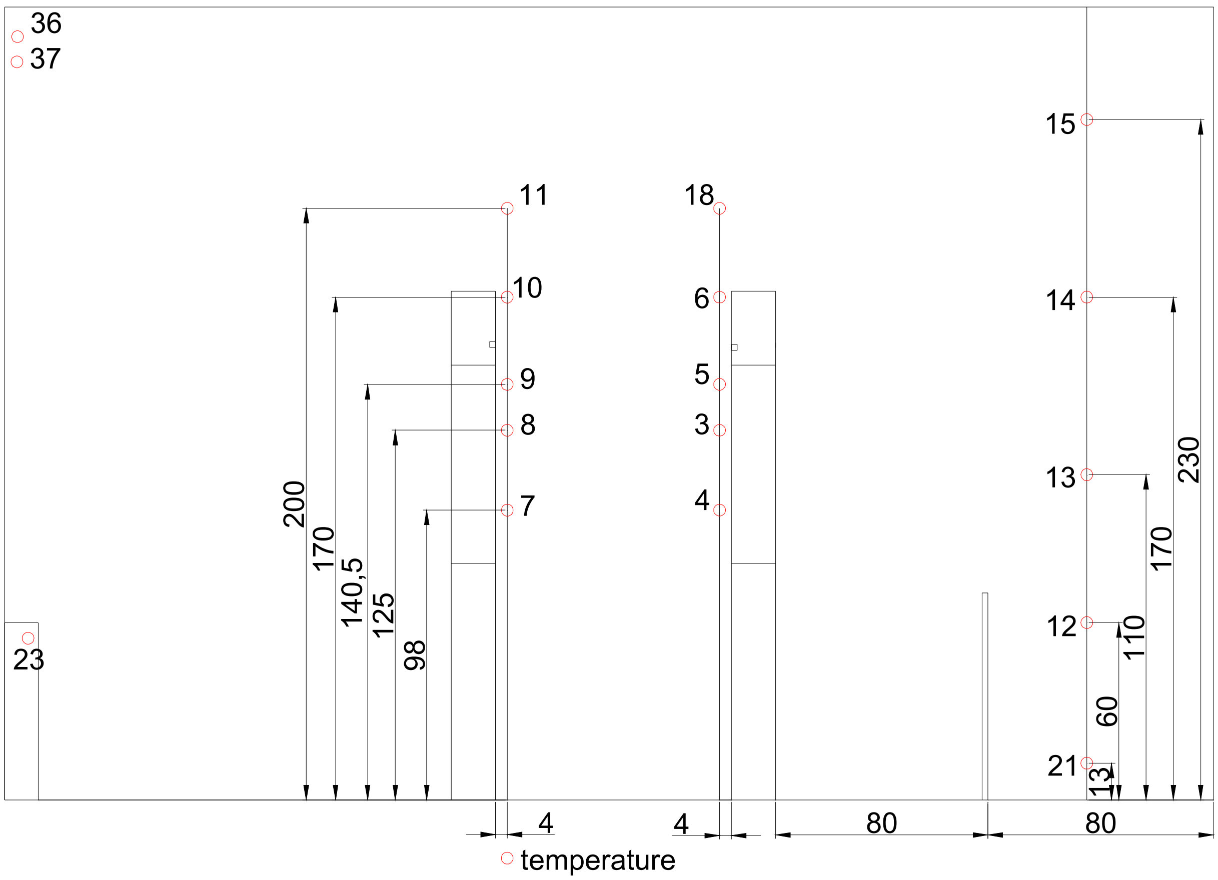


Figure 3.9 Positions of thermocouples (front view)

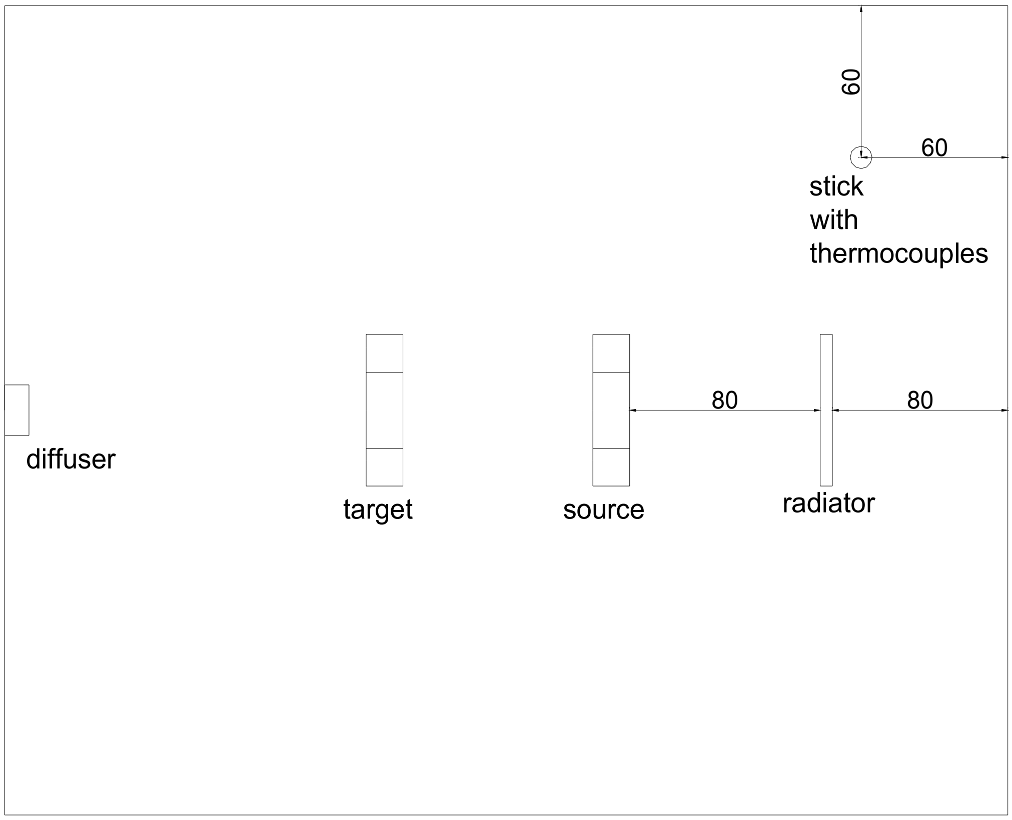


Figure 3.10 Positions of the stick to measure vertical gradient in the corner (top view)

Air velocity

Velocity is measured using 7 hot sphere anemometers . Measuring points are located at different heights by the manikins fronts. Positions of anemometers is seen in figure 3.11

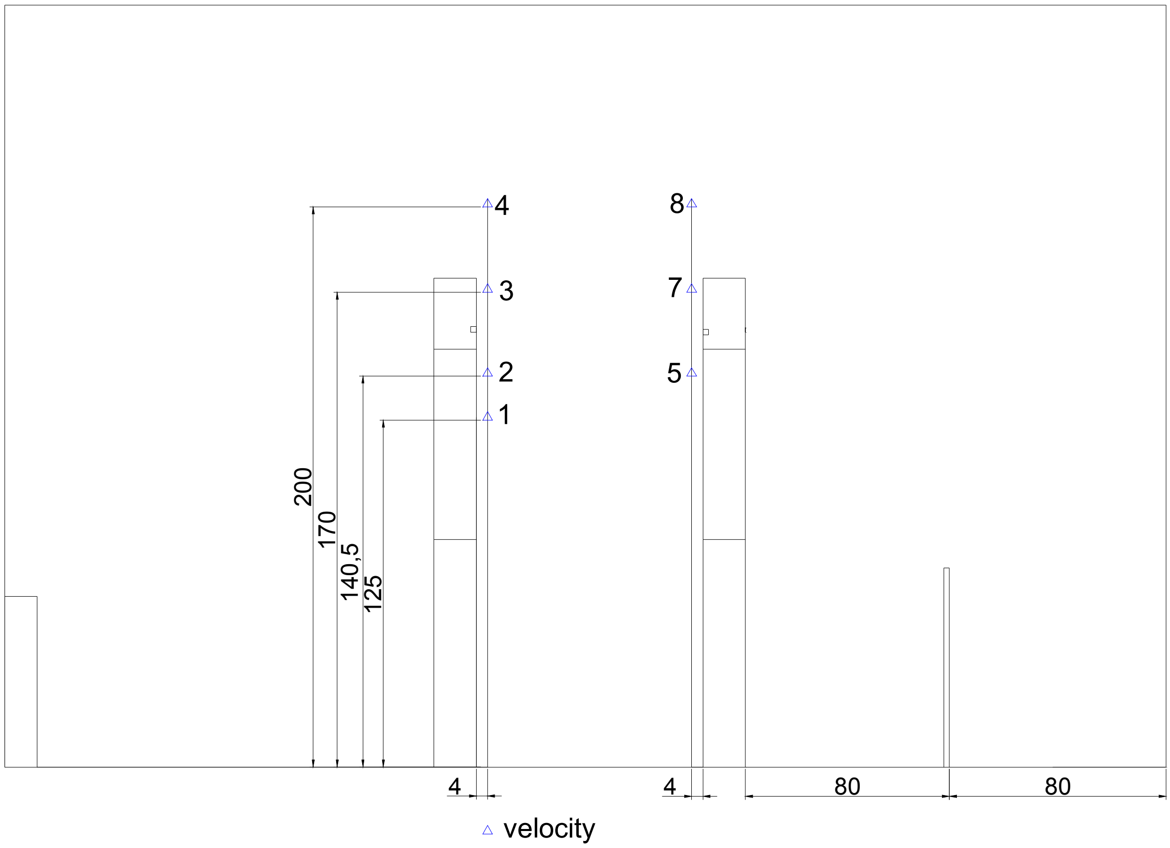


Figure 3.11 Positions of anemometers

Tracer gas concentration

In order to simulate contaminants spreading tracer gas (N_2O) is used. It's supplied together with the exhalation air of source manikin (see figure 3.2). In order to measure concentration of tracer gas 12 tubes connecting to Sample and Doser Monitor are used. Tracer gas is supplied to the mouth of the exhaling manikin in amount of 0,3 l/min. The pressure of N_2O is set for 2,8 bar. Measuring points are located as it is seen in figure 3.12

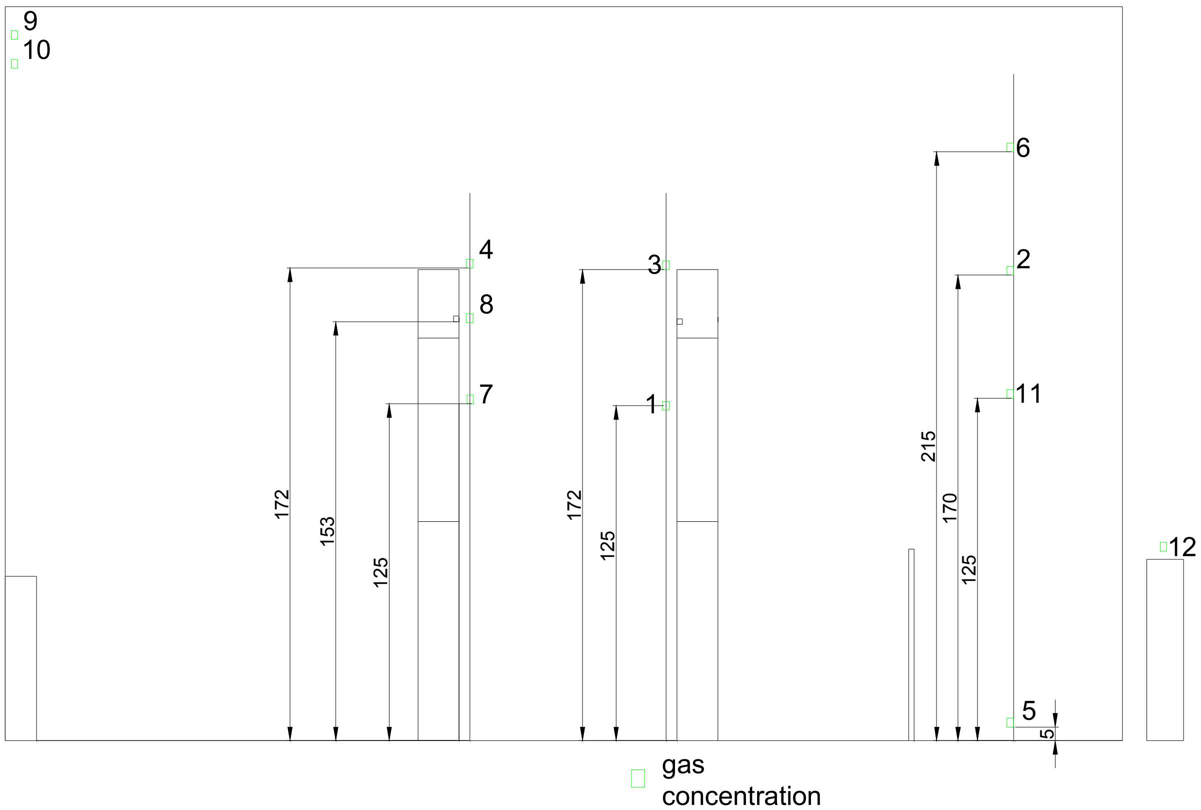


Figure 3.12 Positions of concentration measuring points.

Explanation of chosen measuring points:

No. 1 and 3 – those measuring points are placed close source manikin to know the influence of thermal plume for level of concentration

No.4 – this point is located in the place where exhalation jet from source mouth might have large influence

No. 7 – this point is placed in the chest of target manikin, it shows the level of concentration in the place from where a person inhales the most amount of air

No. 8 – this point located in the tube connecting thermal manikin to its artificial lung. The tracer gas concentration here represents the amount of contaminant inhaled by a person

No.9 and 10 – those points show the level of concentration in 2 exhaust openings, all of the other points are related to those points to get dimensionless level of concentration

No. 12 – the purpose of this measuring points is monitoring any possible leakage of tracer gas from the bottle

No. 5, 11, 2, 6 – those points represent a gradient of tracer gas concentration

All results of concentration are given dimensionless by means of exposure

$$\text{Exposure} = c_p/c_e$$

where c_p is the concentration level at a given point

c_e is the concentration level in the return opening

3.7 List of measurements

No.	Measurement	Description
1	Face35	Two standing manikins, facing each other, distance from nose to nose 35 cm
2	Face50	-‘’- 50cm
3	Face80	-‘’- 80cm
4	Face110	-‘’- 110cm
5	Back35	Two standing manikins, one facing the other’s back, distance from nose to back 35cm
6	Back50	-‘’- 50cm
7	Back80	-‘’- 80cm
8	Back110	-‘’- 110cm
9	Cross35	Two standing manikins, one facing the other’s side, distance from nose to nose 35 cm
10	Cross50	-‘’- 50cm
11	Cross80	-‘’- 80cm
12	Cross110	-‘’- 110cm
13	Sit50	Two manikins facing each other, one standing, the other sitting, horizontal distance from nose to nose 50cm
14	Sit100	-‘’- 110cm
15	1man0	One manikin facing radiator, without heating
16	1man94	One manikin facing radiator, with heating equal to 94 W
17	1man120	One manikin facing radiator, with heating equal to 120W
18	1manexh	Investigation of exhalation jet

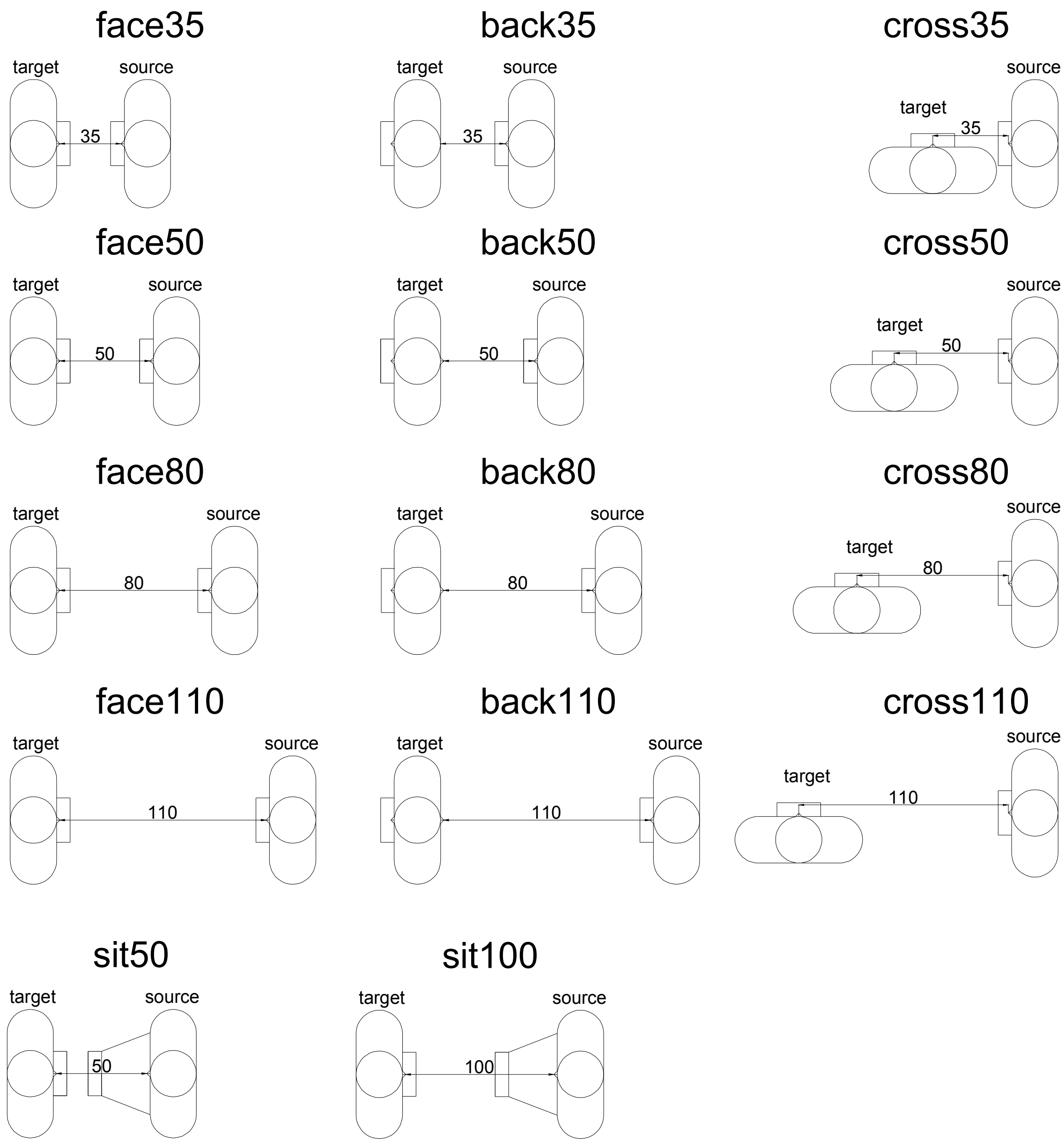


Figure 3.13 Sketches of manikins positions

4. Results for two manikins

4.1 Temperature and tracer gas concentration distribution

4.1.1 Face to face

Manikins are both standing facing each other. Distance between them is changed from 35 till 110 cm but only the target manikin is moved. The distance is measured from the tip of source manikin's nose to the tip of target manikin's nose. A sketch is given in figure 4.1

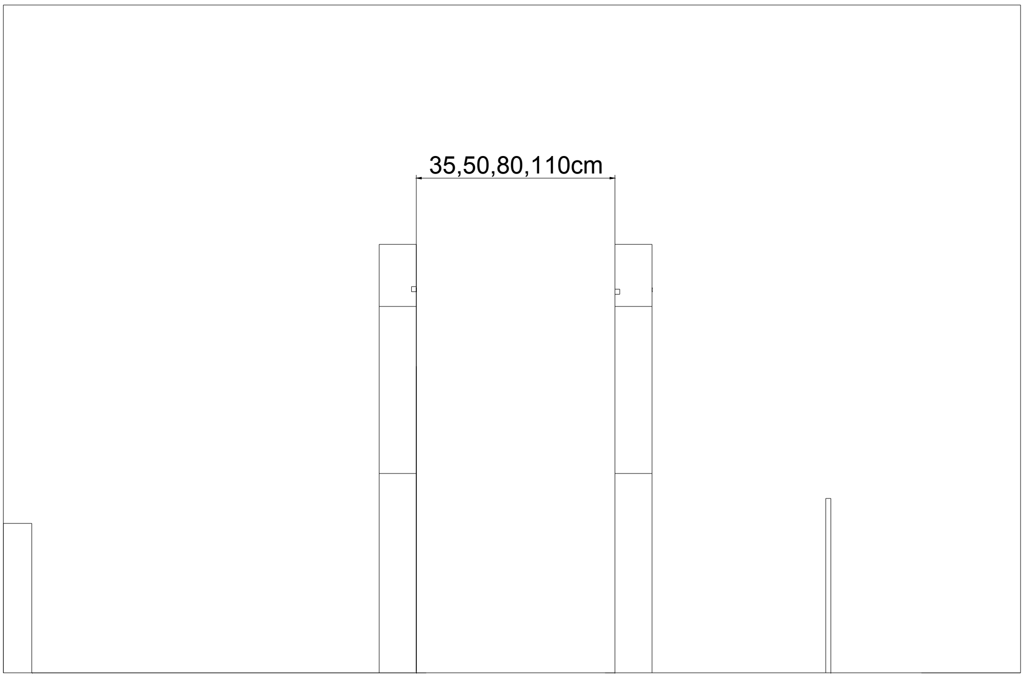


Figure 4.1 Schema of positions of two standing manikins facing each other

Energy balance

$Q_{in} = 300+2\cdot 94+2\cdot 2 = 492$ W

$Q_{out} = 0{,}56 \cdot 1005\cdot(23-16{,}5)\cdot 1{,}2 = 483$W

So $Q_{in} \approx Q_{out}$

Temperature

In the figure 4.2 it is seen a vertical temperature gradient. Distribution of temperature for different distances between manikins is almost the same, what means that all tests are made in the same conditions. Manikin positions do not influence the air distribution. Since radiator is the biggest heat source and it's placed in the lower part of the room it's seen that temperature gradient is larger in the lower part and temperature is more constant in the upper part. Temperature gradient is equal to 2,8 °C.

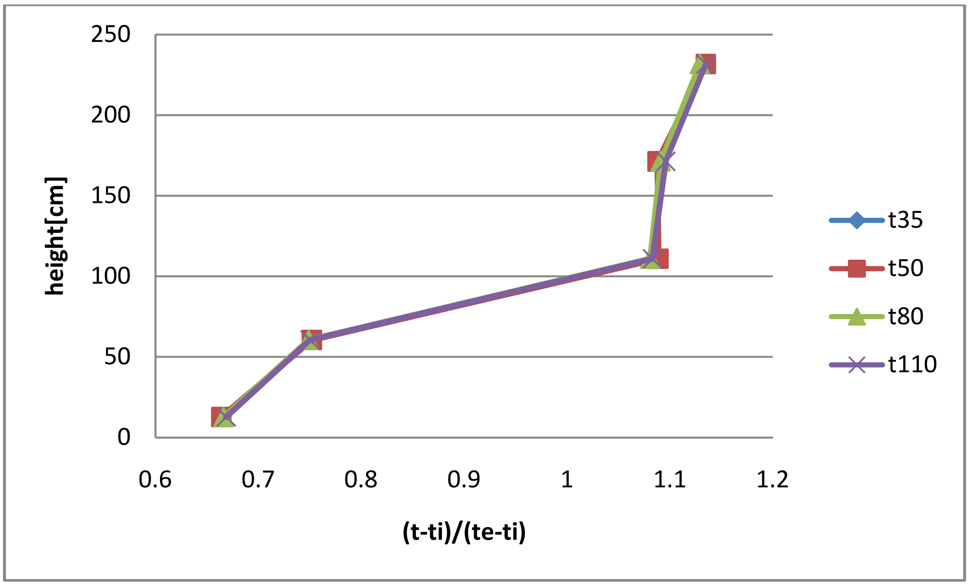


Figure 4.2 Vertical gradient of temperature in the corner of the room

Tracer gas concentration

Vertical gradient of concentration is presented in figure 4.3. It is seen that in all cases concentration of tracer gas is very low close to the floor. The highest point it reaches at the level of manikins chest and then it decreases with height. However it is suspected that the highest point is at the height of 150cm (the level of the mouth) but that point is not measured. The reason of the decrease of concentration with height in the top part of the room might be not strong enough plume, which disintegrates at a lower level. Contaminants are trapped at this level and then slowly transported to the upper part of the room.[6] It might be seen as well that distance between manikins has small influence on the concentration gradient in the corner of the room.

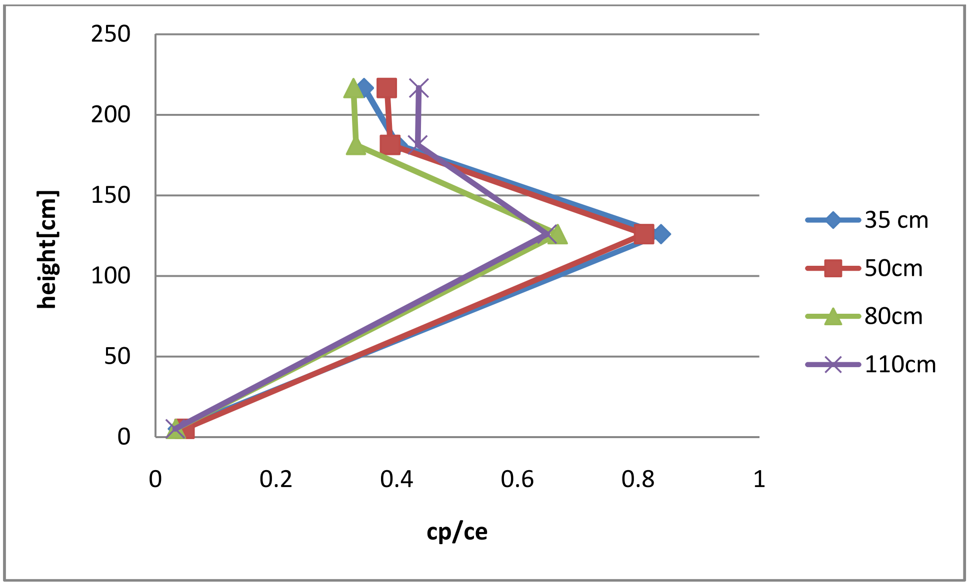


Figure 4.3 Vertical gradient of tracer gas concentration in the corner of the room

Looking at horizontal gradient of concentration 170 cm above the floor it might be seen that the highest concentration is at point no. 4, which is placed above the head of target manikin. The reason of that is that the exhalation jet is bent up towards point no. 4 because of thermal plume of target manikin and higher temperature of the exhaled air. The lowest concentration is at point no. 2, which is further in the corner of the room and it is not directly exposed to exhalation jet.

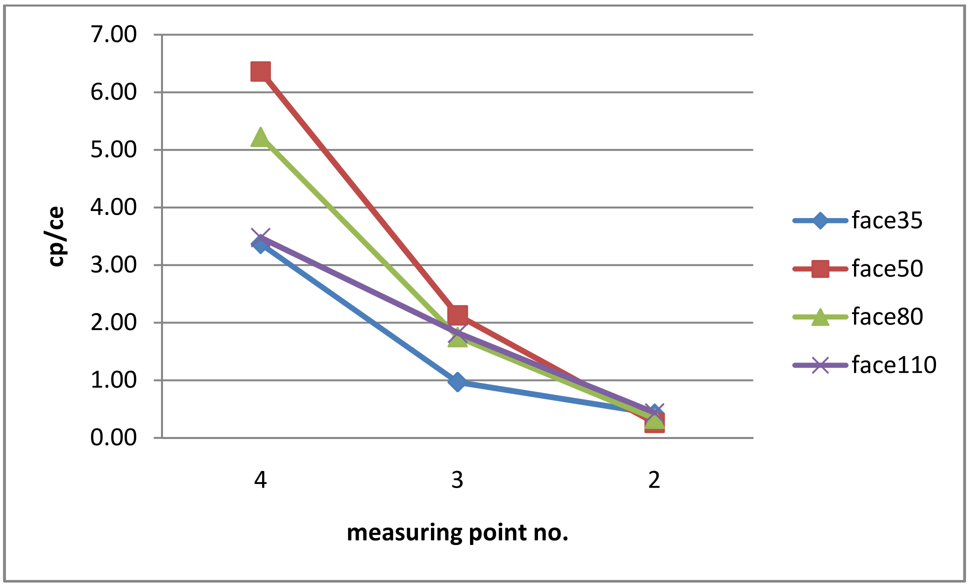


Figure 4.4 Horizontal gradient of tracer gas concentration at the height of 170 cm above the floor

Looking at horizontal gradient of concentration 125 cm above the floor(chest level) it is seen that generally concentration level is relatively low. Especially measuring points at chests of source and target manikins show very low level of concentration. The reason of that are thermal plumes of manikins and presence of displacement ventilation.

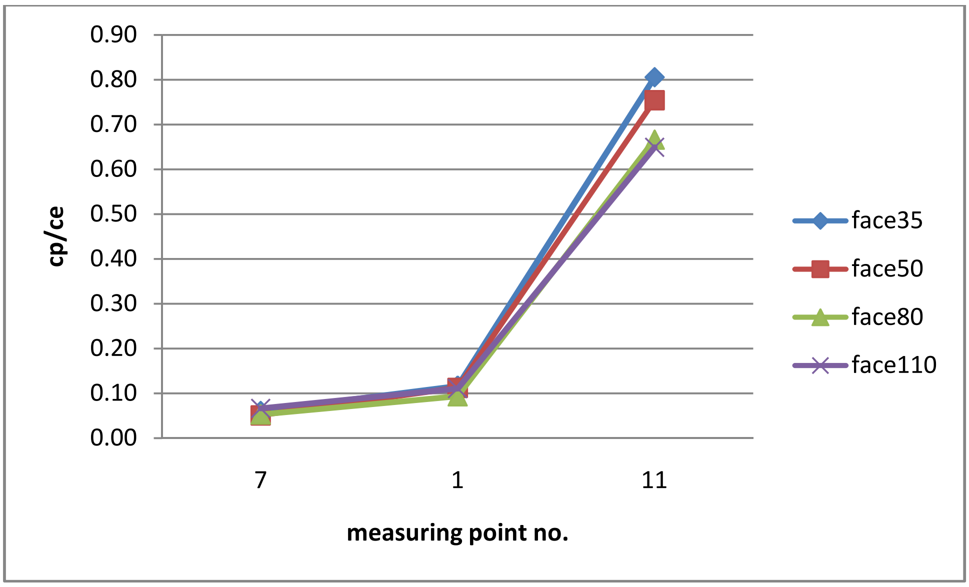


Figure 4.5 Horizontal gradient of tracer gas concentration at the height of 125cm above the floor

4.1.2 Face to back

Manikins are both standing, the source manikin is facing the target manikin's back. A distance between them is changed from 35 till 110 cm. The distance is measured from the tip of target manikin's nose to the source manikin's back. A schema is given in figure 4.6

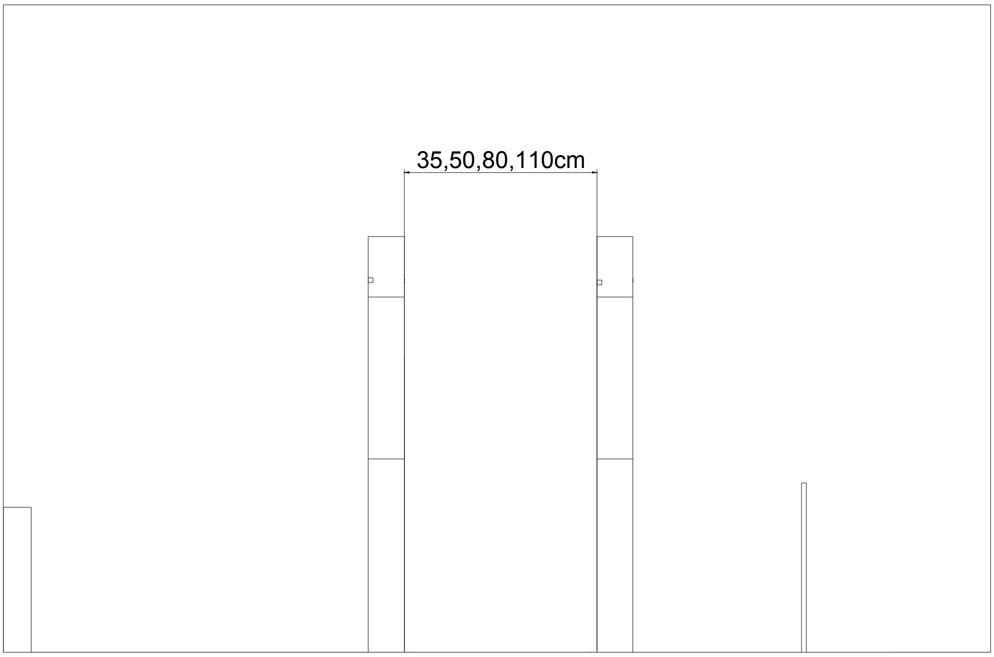


Figure 4.6 Schema of positions of two standing manikins, one facing the other back

Energy balance

Q_{in} = 300+2·94+2·2 = 492 W

Q_{out} = 0,056 ·1005·(22,5-16,1)·1,2 = 475W

So $Q_{in} \approx Q_{out}$

Temperature

In the figure 4.7 it is seen vertical temperature gradient. Distribution of temperature for different distances between manikins is almost the same, which means that all tests are made in the same conditions. Manikin positions do not influence the air distribution. Temperature gradient is equal to 3,0 °C.

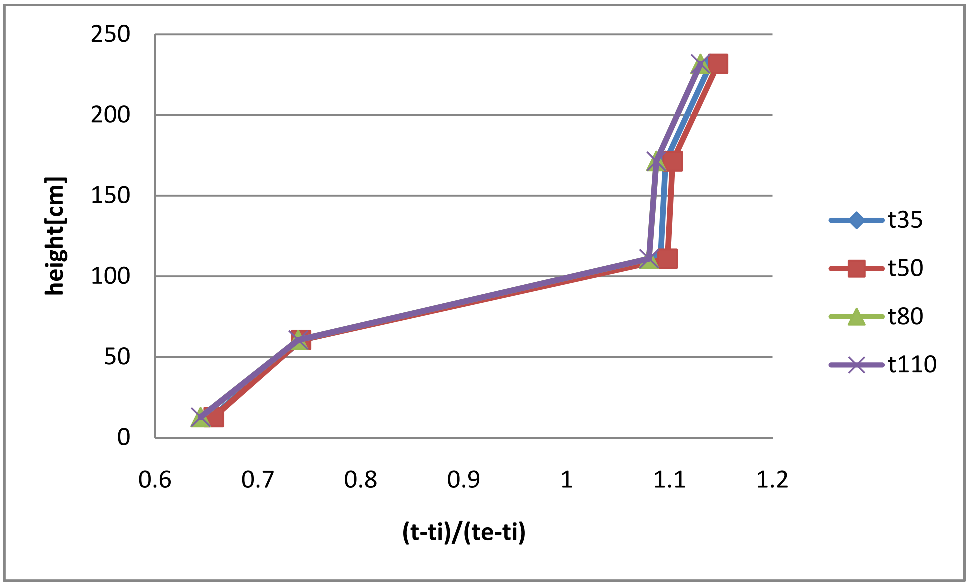


Figure 4.7 Vertical gradient of temperature in the corner of the room

Tracer gas concentration

Vertical gradient of concentration is presented in figure 4.8. It is seen that in all cases concentration of tracer gas is very low close to the floor. The highest point it reaches at the level of manikins chest and then it decreases with height. It might be seen as well that distance between manikins has small influence on the concentration gradient in the corner of the room. Closer the manikins are higher the concentration is obtained.

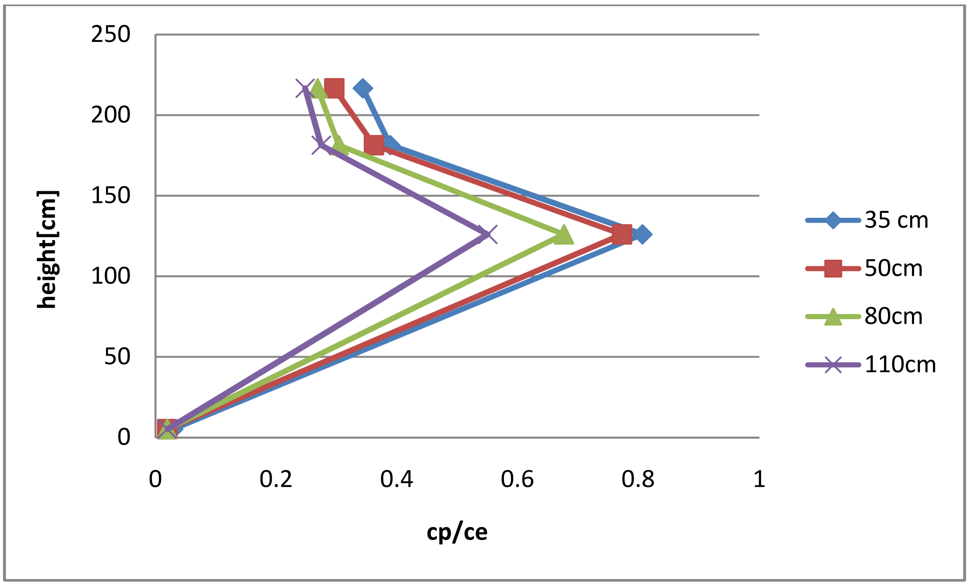


Figure 4.8 Vertical gradient of tracer gas concentration in the corner of the room

Looking at horizontal gradient of concentration 170 cm above the floor it might be seen that the highest concentration is at point no. 4, which is placed above the head of target manikin. The reason of that is that the exhalation jet is bent up towards point no. 4 because of the thermal plume of target manikin and higher temperature of exhaled air. The lowest concentration is at point no. 2, which is further in the corner of the room and it is not directly exposed to exhalation jet.

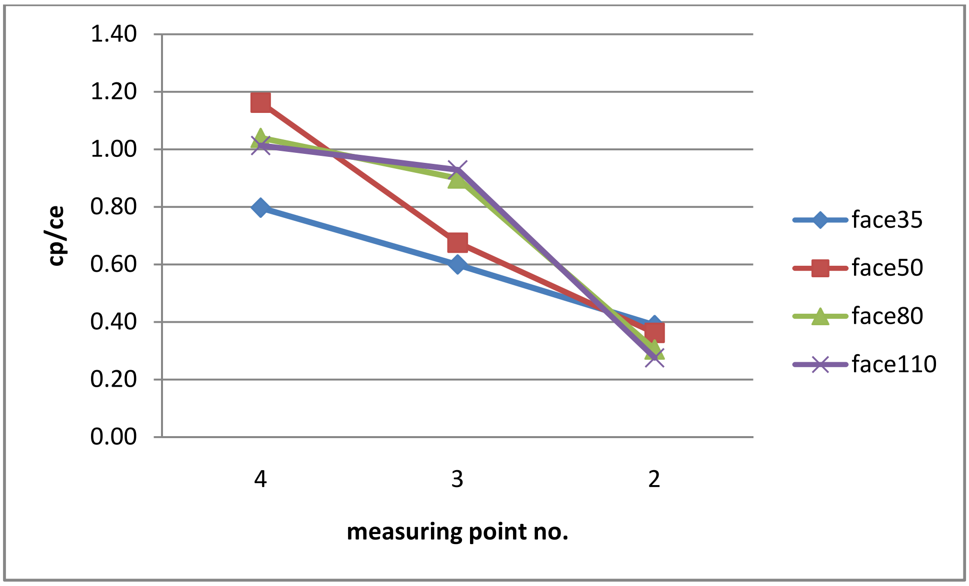


Figure 4.9 Horizontal gradient of tracer gas concentration at the height of 170cm above the floor

Looking at horizontal gradient of concentration 125 cm above the floor(chest level) it is seen that generally concentration level is relatively low. Especially measuring points at chests of source and target manikins show very low level of concentration. The reason of that are thermal plumes of manikins and presence of displacement ventilation.

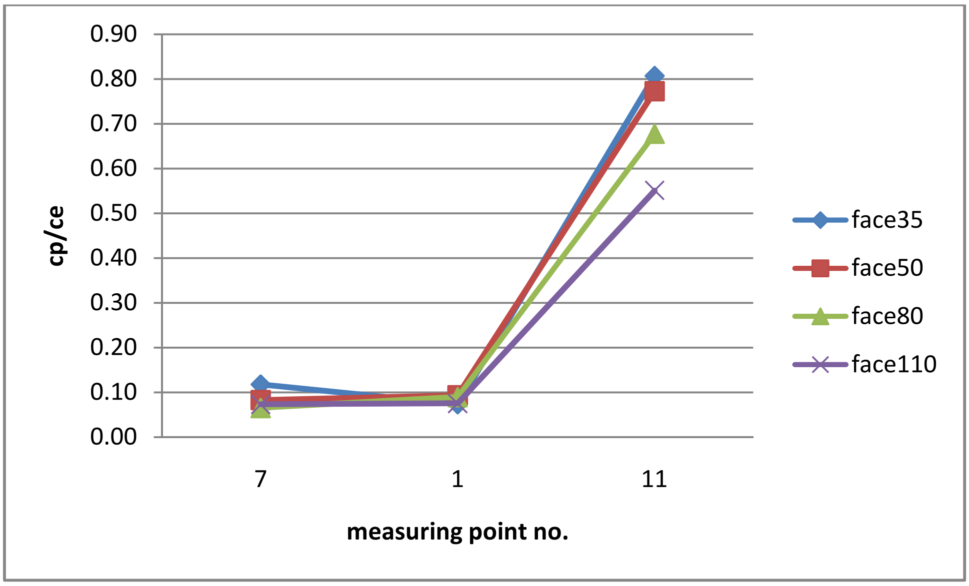


Figure 4.10 Horizontal gradient of tracer gas concentration at the height of 125cm above the floor

4.1.3 Cross

Manikins are both standing, one facing the other side. A distance between them is changed from 35 till 110 cm. The distance is measured from the tip of source manikin's nose to the tip of target manikin's nose. A sketch is given in figure 4.11

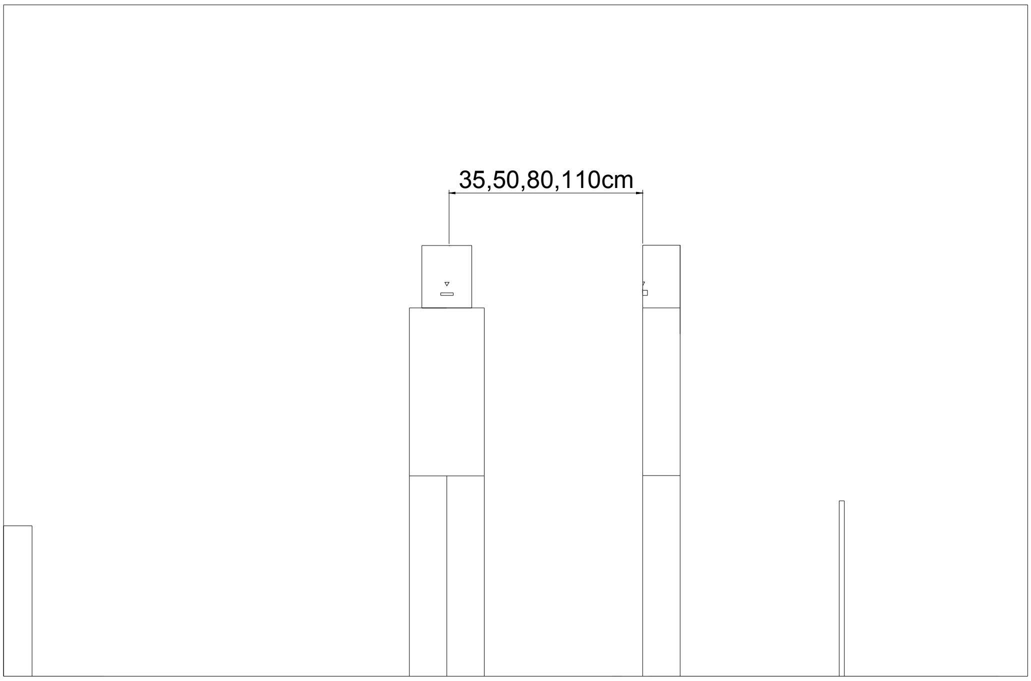


Figure 4.11 Sketch of positions of two standing manikins, one facing the other side

Energy balance

Q_{in} = 300+2·94+2·2 = 492 W

Q_{out} = 0,56 ·1005·(22,5-16,1)·1,2 = 473W

So $Q_{in} \approx Q_{out}$

Temperature

In the figure 4.12 it is seen a vertical temperature gradient. The distribution of temperature for different distances between manikins is almost the same, what means that all tests are made in the same conditions. The temperature gradient is equal to 3,1 °C.

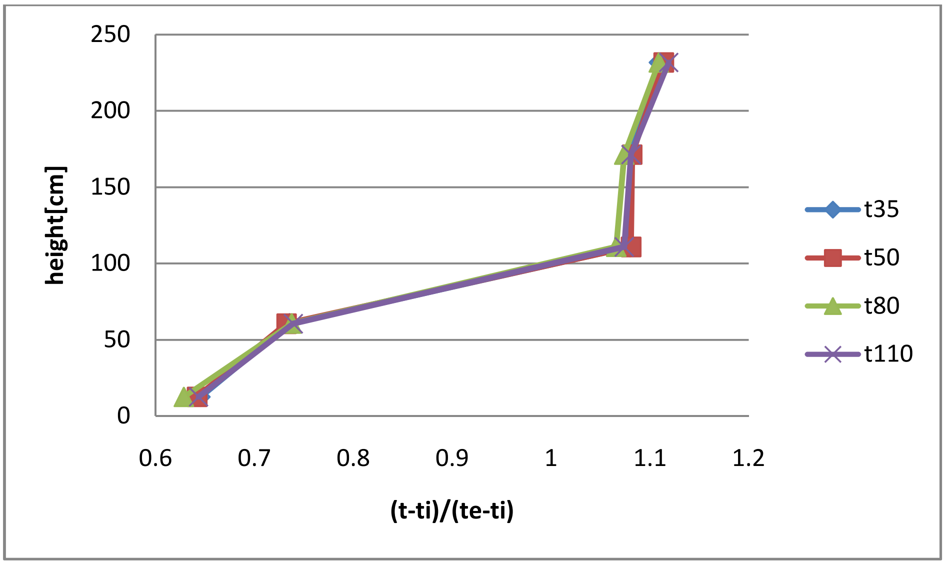


Figure 4.12 Vertical gradient of temperature in the corner of the room

Tracer gas concentration

A vertical gradient of concentration is presented in figure 4.13. It is seen that in all cases concentration of tracer gas is very low close to the floor. The highest point it reaches at the level of manikins chest and then it decreases with height. It might be seen as well that distance between manikins has small influence on the concentration gradient in the corner of the room.

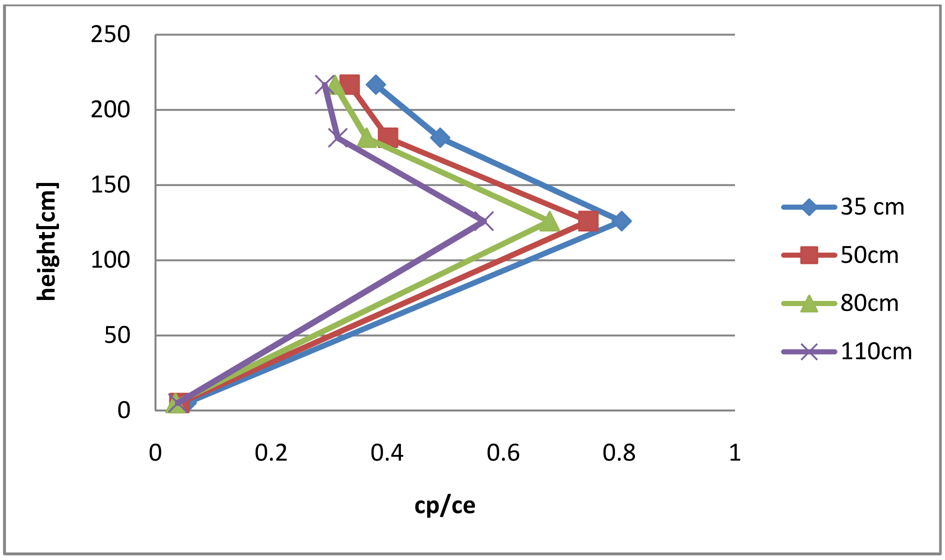


Figure 4.13 Vertical gradient of tracer gas concentration in the corner of the room

Looking at horizontal gradient of concentration 170 cm above the floor it might be seen that the highest concentration is at point no. 4, which is placed above the head of target manikin. The reason of that is that the exhalation jet is directed towards point no. 4 because of thermal plume of target manikin and higher temperature of exhaled air. The lowest concentration is at point no. 2, which is further in the corner of the room and it’s not directly exposed to exhalation jet.

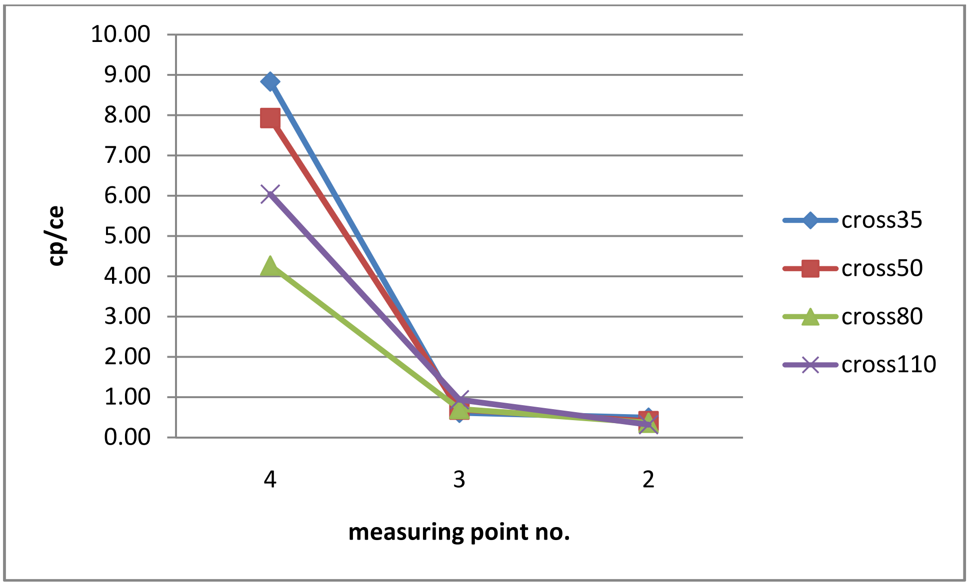


Figure 4.14 Horizontal gradient of tracer gas concentration at the height of 170cm above the floor

Looking at horizontal gradient of concentration 125 cm above the floor(chest level) it is seen that generally concentration level is relatively low. Especially measuring points at chests of source and target manikins show very low level of concentration. The reason of that are thermal plumes of manikins and presence of displacement ventilation.

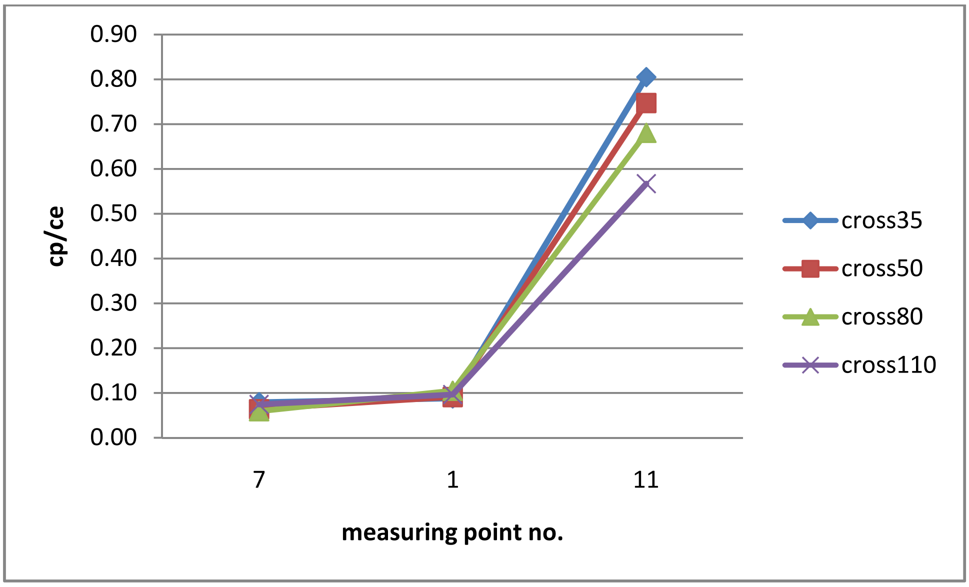


Figure 4.15 Horizontal gradient of tracer gas concentration on the level of 125cm above the floor

4.1.4 Sitting case

One manikin is sitting, it is a source of contaminants the other is standing and facing it and it is a target. A distance between them is changed and it is equal to 50 and 100cm. The distance is measured horizontally between the tip of source manikin's nose and the target manikin's nose. A schema is given in figure 4.16

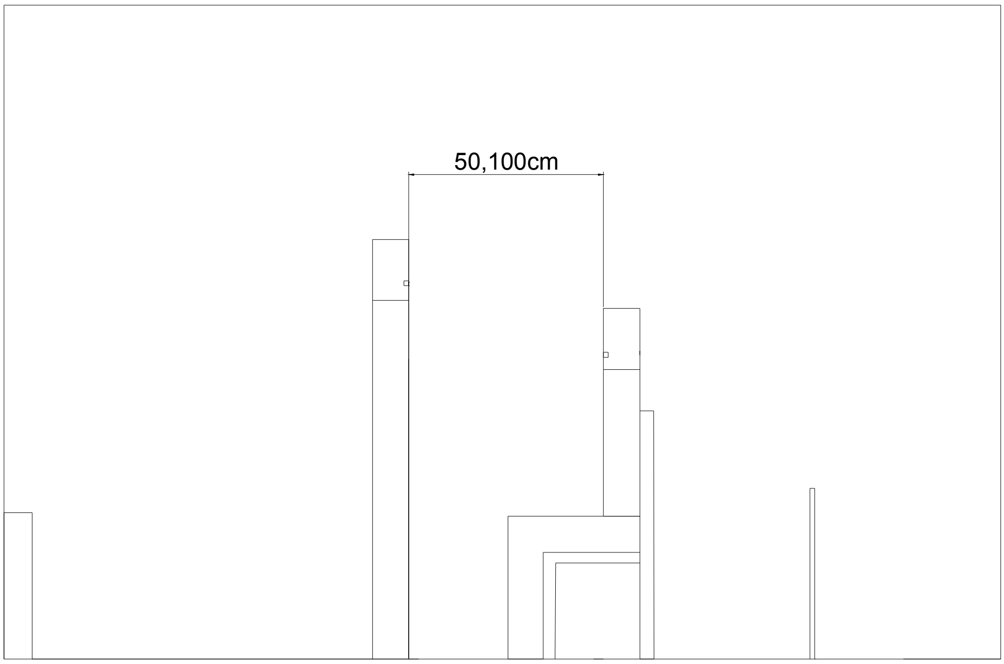


Figure 4.16 The schema of two facing each other manikins, one is sitting and the other standing

Energy balance

Q_{in} = 300+2·94+2·2 = 492 W

Q_{out} = 0,56 ·1005·(22,1-15,6)·1,2 = 483W

So $Q_{in} \approx Q_{out}$

Temperature

In the figure 4.17 it is seen vertical temperature gradient. Distribution of temperature for different distances between manikins is almost the same, what means that both tests are made in the same conditions. Temperature gradient is equal to 2,9 °C.

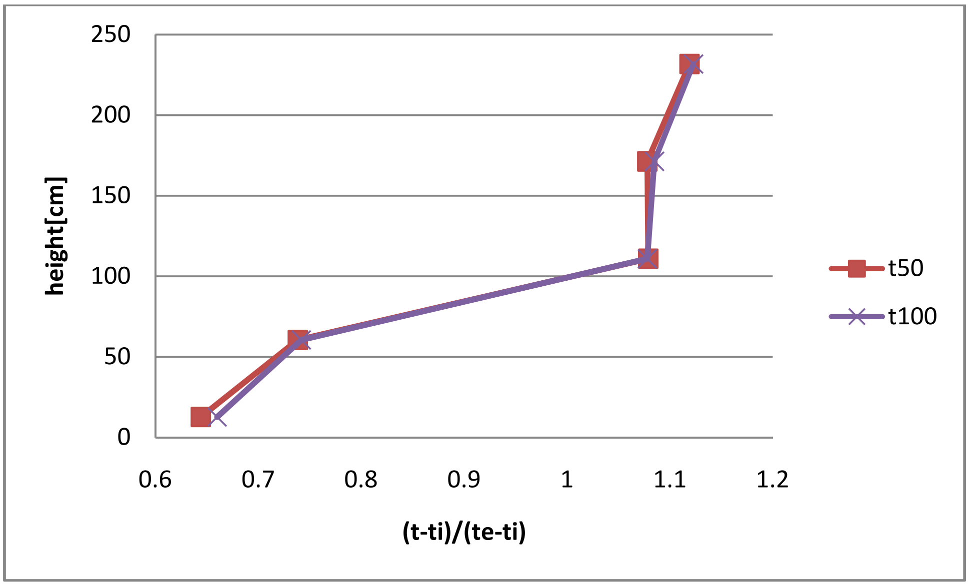


Figure 4.17 Vertical gradient of temperature for case one standing and one sitting manikin

Tracer gas concentration

Vertical gradient of concentration is presented in figure 4.18. It is seen that in all cases concentration of tracer gas is very low close to the floor. The highest point it reaches at the level of manikins chest and then it decreases with height. Concentration of tracer gas at the chest level is almost twice higher in case of distance 100 cm between manikins than for 50 cm. It indicates that in case of 50 cm most contaminants are captured by thermal plume of target manikin and lifted up to the higher zone. Whereas in case of 100 cm contaminants are spread on the level of source manikin mouth.

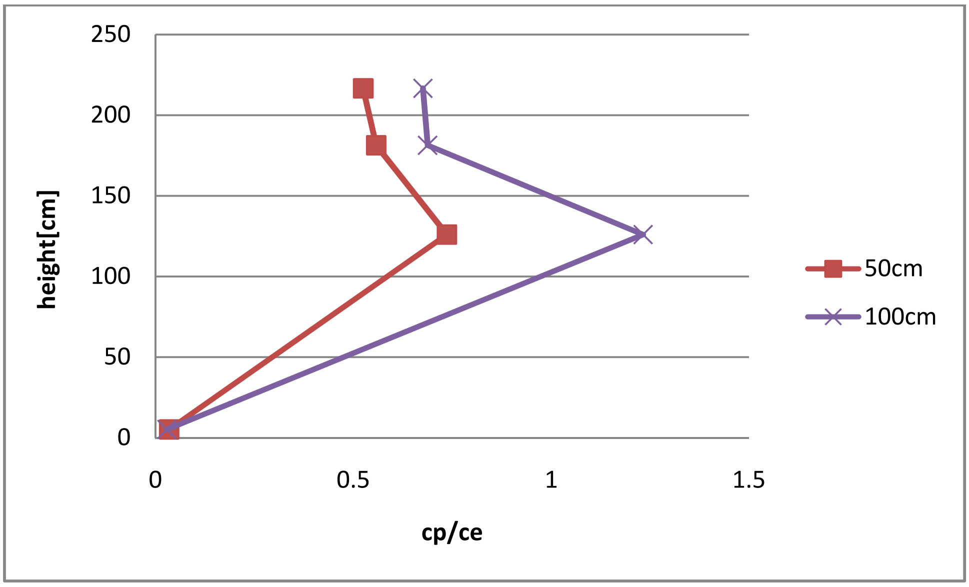


Figure 4.18 Vertical gradient of tracer gas concentration

Looking at horizontal gradient of concentration 170 cm above the floor(chest level) it is seen that concentration at point no. 4 is lower than in standing cases. The reason of that might be that point no. 4 in this case is not directly exposed to exhalation jet. Distance between manikins has small influence on concentration level at point no. 4 , which is higher for distance 50 cm between manikins.

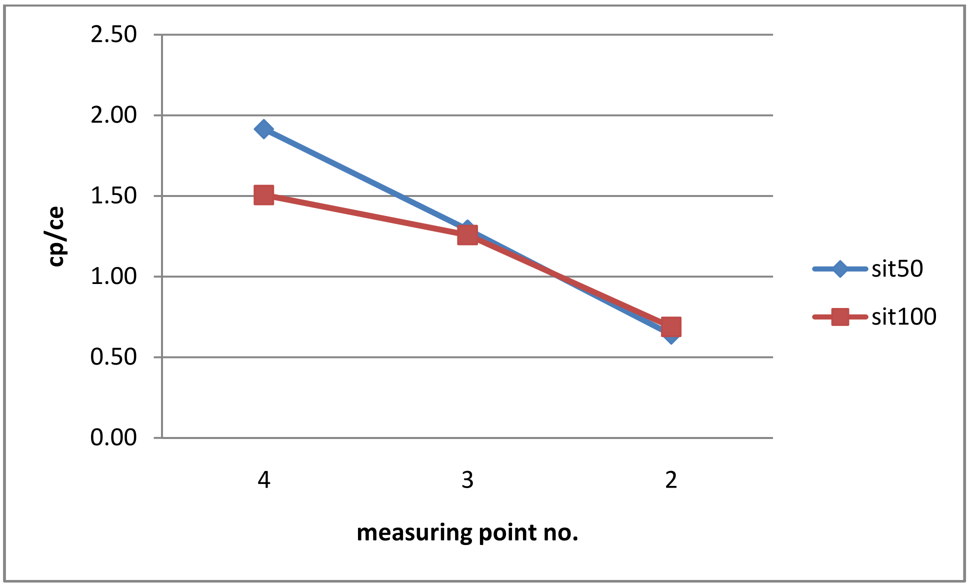


Figure 4.19 Horizontal gradient of tracer gas concentration on the level of 170cm above the floor

Looking at horizontal gradient of concentration 125 cm above the floor(chest level) it is seen that generally concentration level is much higher than in standing cases. The reason of that is direction of exhalation jet of source manikin, which is straight to manikins chest.

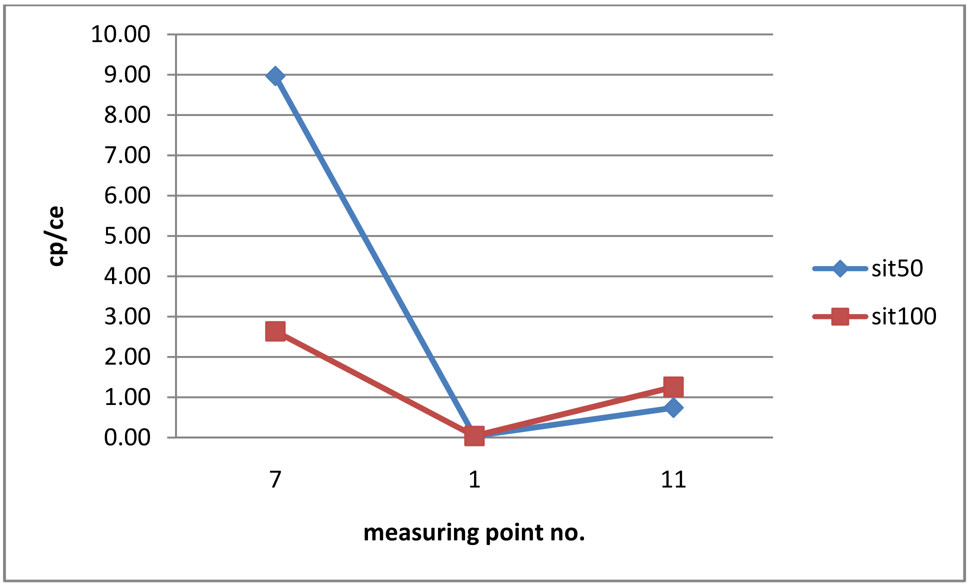
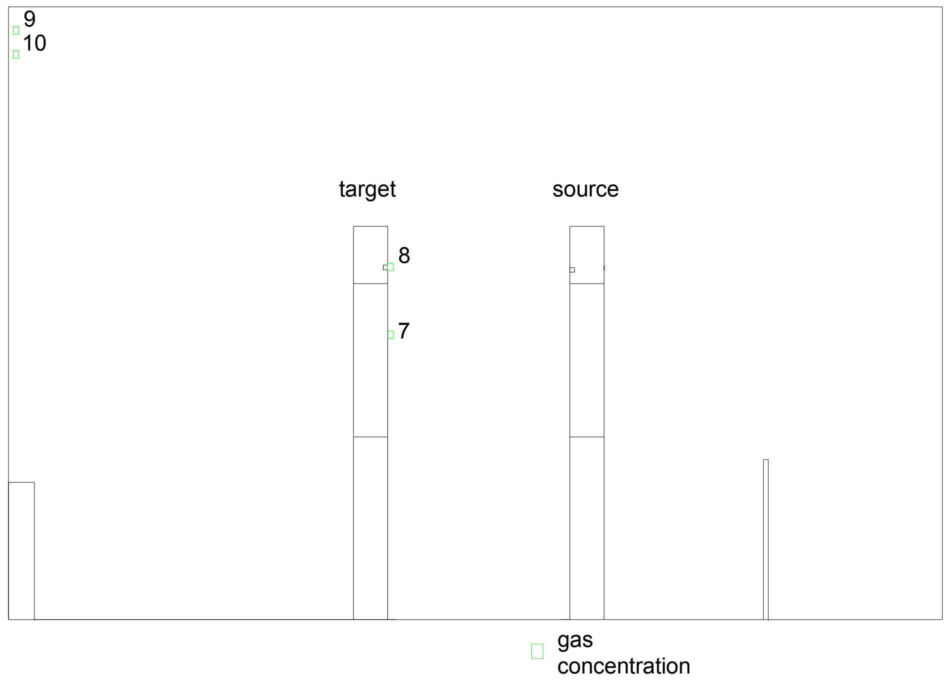


Figure 4.20 Horizontal gradient of tracer gas concentration on the level of 125cm above the floor

4.2 Personal exposure

In order to know the exposure of target manikin to source manikin exhalation jet, concentration is measured in the mouth and on the chest of target manikin as well as in exhaust openings. It is seen in figure 4.21



4.21 Location of measuring points for calculation of exposure

Mouth

Level of tracer gas concentration inhaled by target manikin depends significantly on position of two manikins as well as on distance between them. The highest concentration is noticed in case of two standing manikins facing each other. The reason of such high concentration are large concentration peaks, which are presented in figure 4.27. The lowest concentration is in “back” case, where target manikin is not directly exposed to exhalation jet from source manikins mouth. The distance between manikins is important only in “face” and “cross” cases, where exposure decreases with distance. In “back” and “sitting” cases investigated range of distance between manikins doesn’t impact the results.

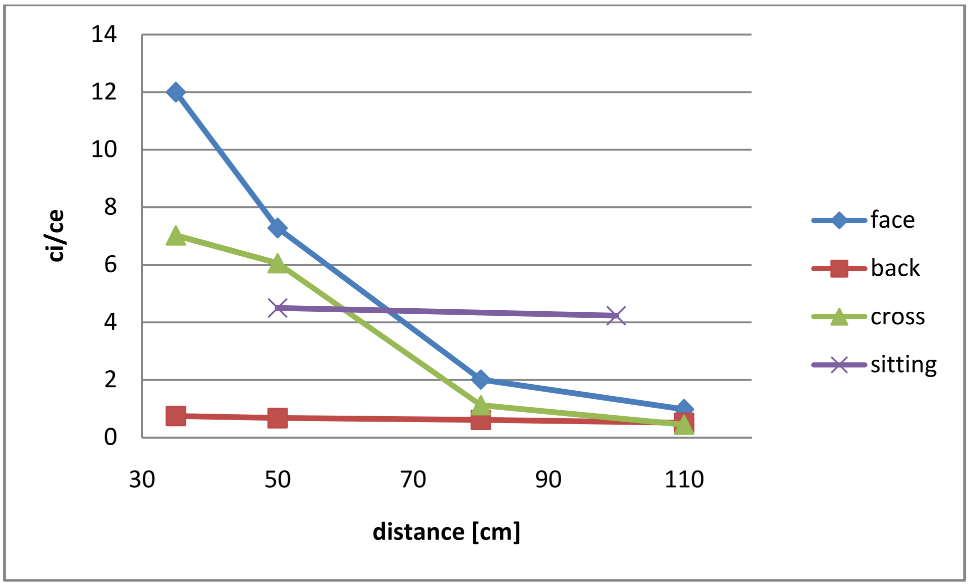


Figure 4.22 Relation between exposure in a mouth of target manikin and a distance between manikins

Where C_i - concentration in inhaled air

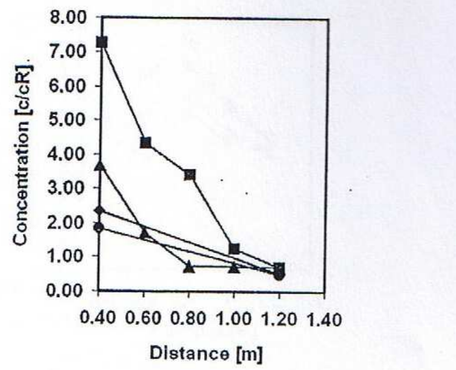
C_e - concentration in exhaust opening

<u>Comparison of the exposure results to results obtained by other students in the past</u>

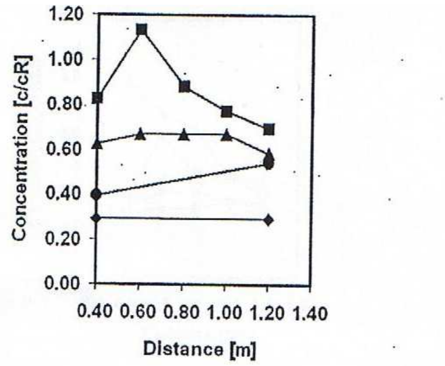
Figure 4.24 show the results obtained in the past by other students. Conditions used by them differ a bit with those used in this project (see figure 4.23). Lines marked with black square are taken into consideration. When comparing the results it is seen that values of concentration exposure obtained in the past are lower than the latest values. Maximum value equals 7 when in the measurements from 2009 it is equal to 12. Also in “cross” case results of concentration are higher in the latest measurements. The main reason of the differences is probably different exhalation airflow. Furthermore precise direction of exhalation jet influence the results (see chapter 6.1).

Case	Air change rate[h^{-1}]	Exhalation airflow [l/min]	Heat load[W]
2009	5,7	11	493
The past	3,5	6,8	480

Figure 4.23 Conditions during experiments



Concentration in the occupied zone and exposure of the target manikin.
(●) c_{oc}/c_R*, occupied zone for exhalation through mouth*
(◆) c_{oc}/c_R*, occupied zone for exhalation through nose*
(▲) c_{exp}/c_R*, exposure for exhalation through nose*
(■) c_{exp}/c_R *exposure for exhalation through mouth*
The measurements are made in a room with a displacement air distribution system. The two manikins are standing face to face.



Concentration in the occupied zone and exposure of the target manikin.
(●) c_{oc}/c_R*, occupied zone for exhalation through mouth*
(◆) c_{oc}/c_R*, occupied zone for exhalation through nose*
(▲) c_{exp}/c_R*, exposure for exhalation through nose*
(■) c_{exp}/c_R *exposure for exhalation through mouth*
The measurements are made in a room with a displacement air distribution system. The two manikins are standing perpendicular to each other.

Figure 4.24 Results of relation between exposure in a mouth of target manikin and a distance between manikins for case “face to face”(left) and “cross”(right) in a room with displacement ventilation obtained in the past

Chest

Personal exposure at the chest of target manikin depends on position of source manikin, whether it is sitting or standing . In case of two standing manikins exposure index is very low in all three cases. It is caused by displacement ventilation, thermal plume of target manikin as well as hot exhalation air from thermal manikin, which don’t allow contaminants to get to the chest area of target manikin. In case when source manikin is sitting exposure is much higher and its values depends on distance between manikins.

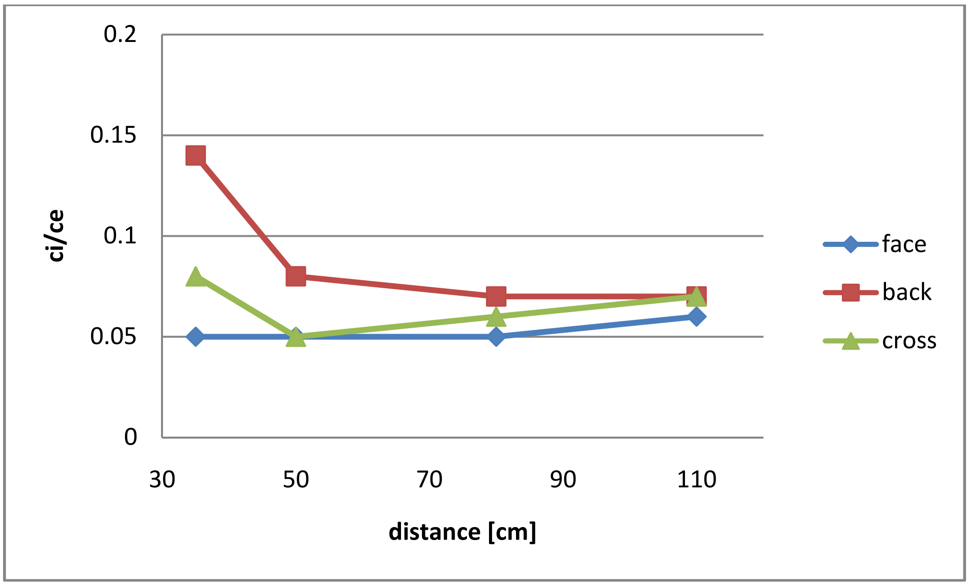


Figure 4.25 Relation between exposure at chest of target manikin and distance between manikins

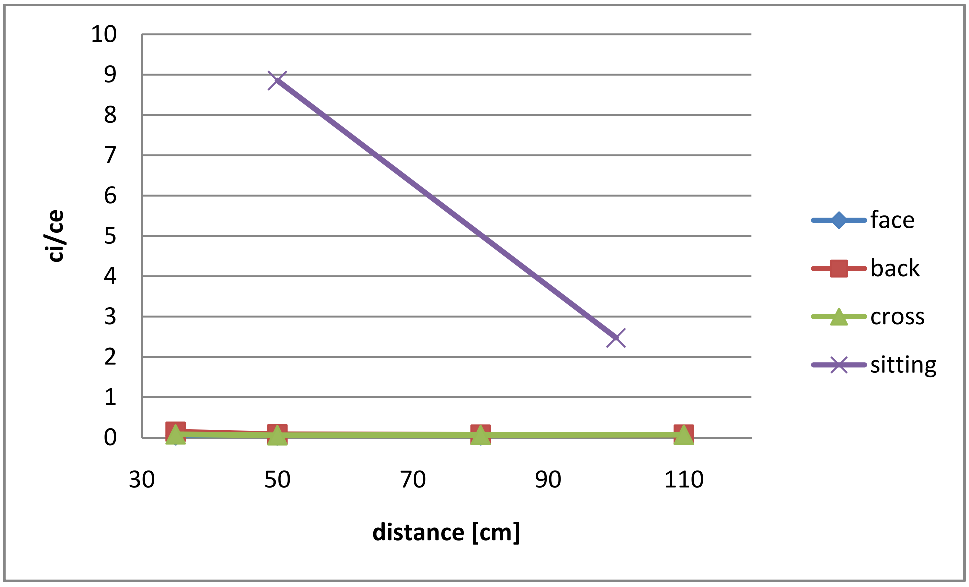
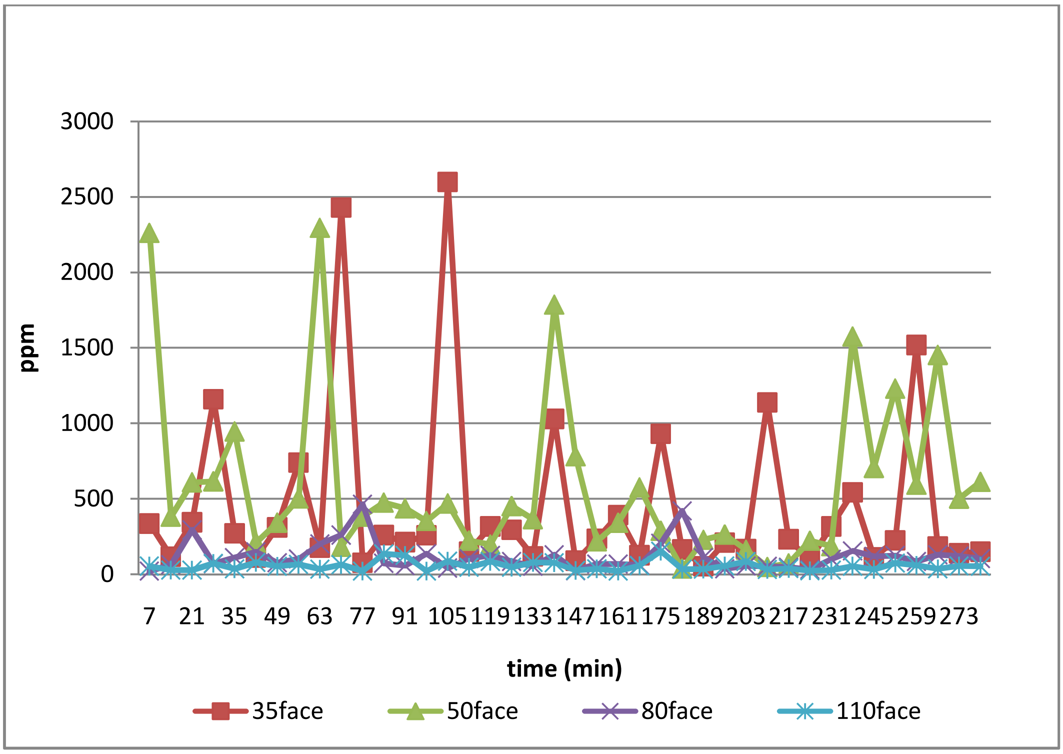


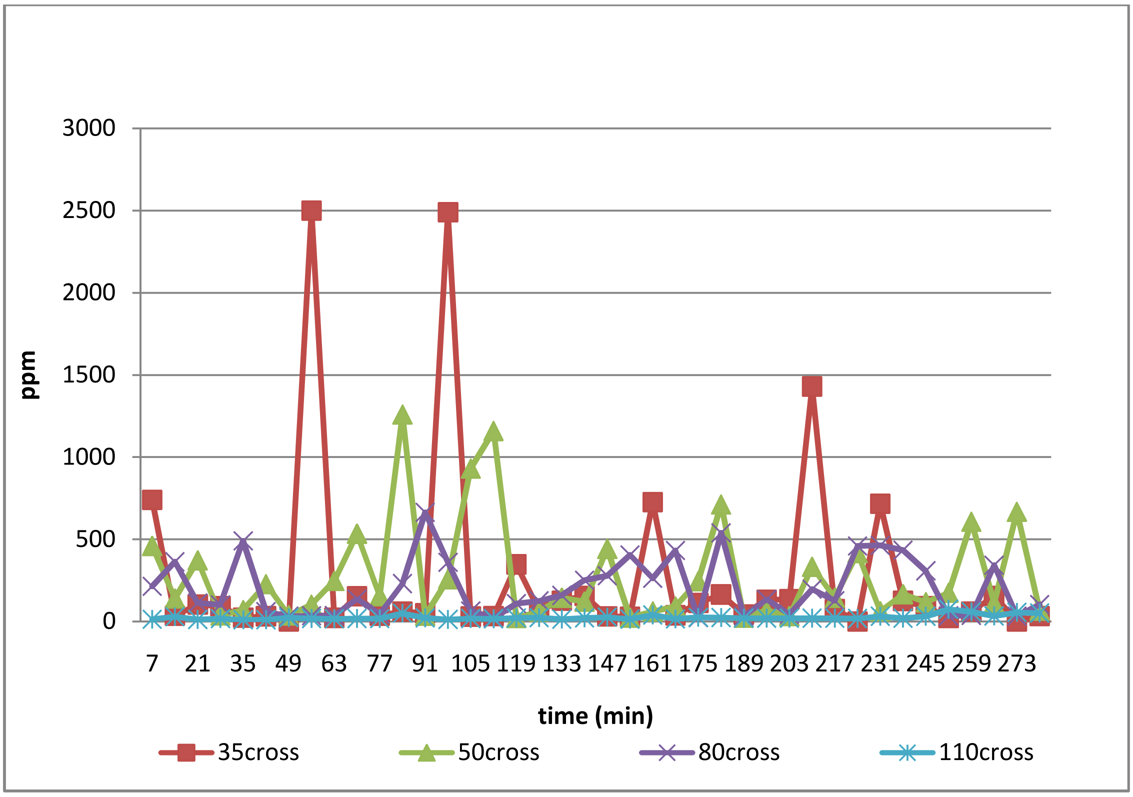
Figure 4.26 Relation between exposure on chest of target manikin and distance between manikins

Peaks of concentration

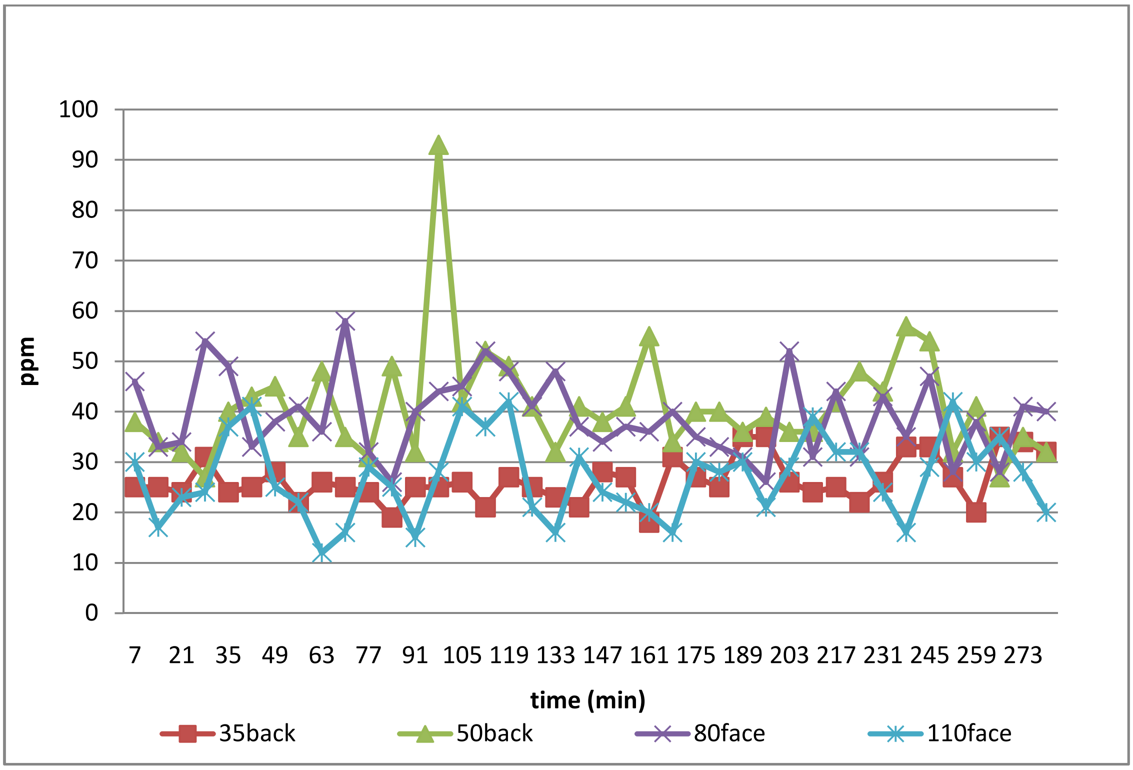
Three figures below present peaks of concentration in the air inhaled by target manikin for cases “face to face” , “back” and “cross”. Peaks appear when large amount of tracer gas concentration gets to target manikins mouth and it is synchronized with work of measuring equipment. As it seen in figure 4.27 in case “face to face” the amount and size of peaks depends on distance between manikins. For 35 and 50 cm peaks achieve the level of 2000 ppm. In “cross” case peaks are slightly smaller but they are also quiet huge. Only in “back” case there aren’t any peaks, which is caused by not direct exposure of target manikin’s mouth to exhalation jet from source manikin’s mouth.



4.27 Peaks of tracer gas concentration in case “face to face"



4.28 Peaks of tracer gas concentration in case “cross”



4.29 Peaks of tracer gas concentration in case “back”

4.3 Comfort parameters next to manikins

4.3.1 Velocity gradients by the manikins fronts

Velocity is measured next to the source and target manikins. Seven anemometers are used and placed as it is seen in figure 3.10.

Face to face

In the figure 4.30 it's seen that the highest velocities are in case when a distance between manikins is equal to 110 cm. In this case distance between the target manikin and the diffuser is very small so horizontal velocity by the ankles is probably higher than in the other cases. It might cause that thermal plume along the body is stronger, what has influence on velocity level.

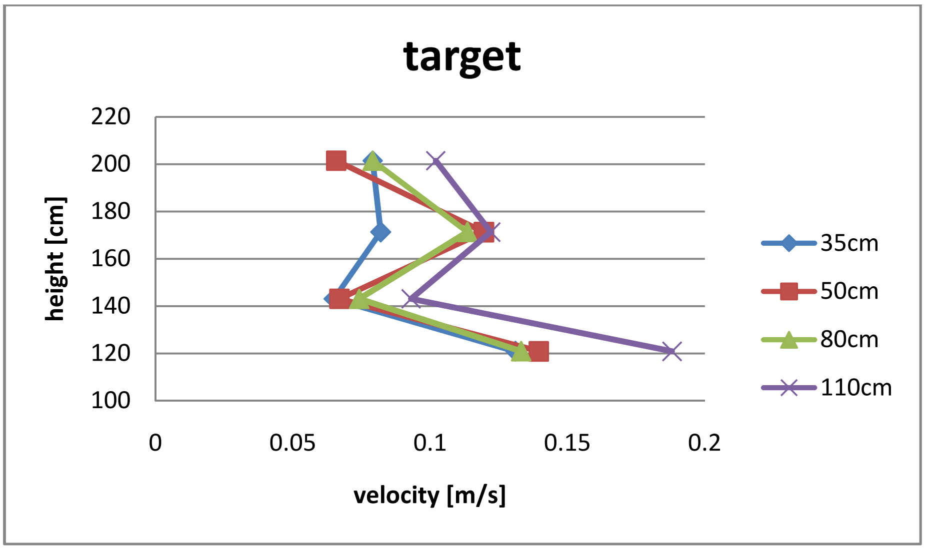


Figure 4.30 Velocity gradient by the target manikin

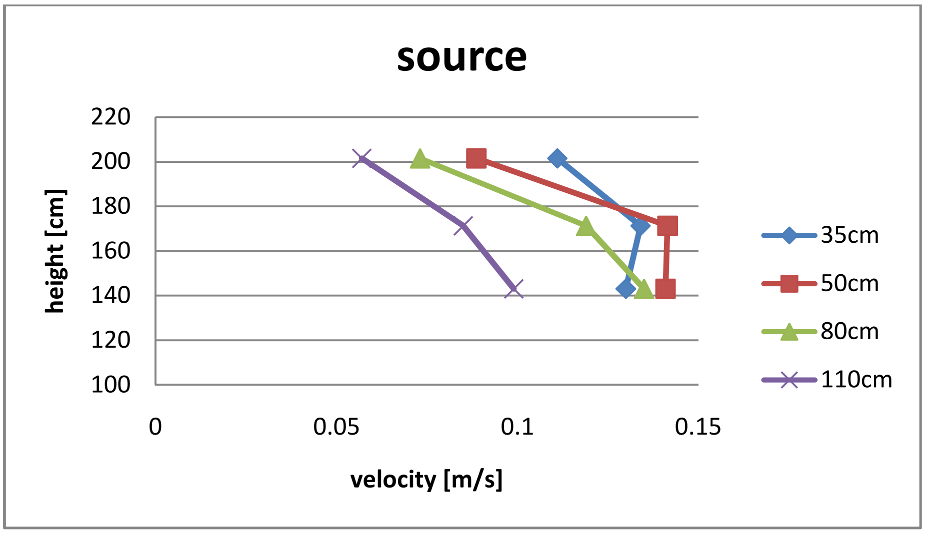


Figure 4.31 Velocity gradient by the source manikin

Face to back

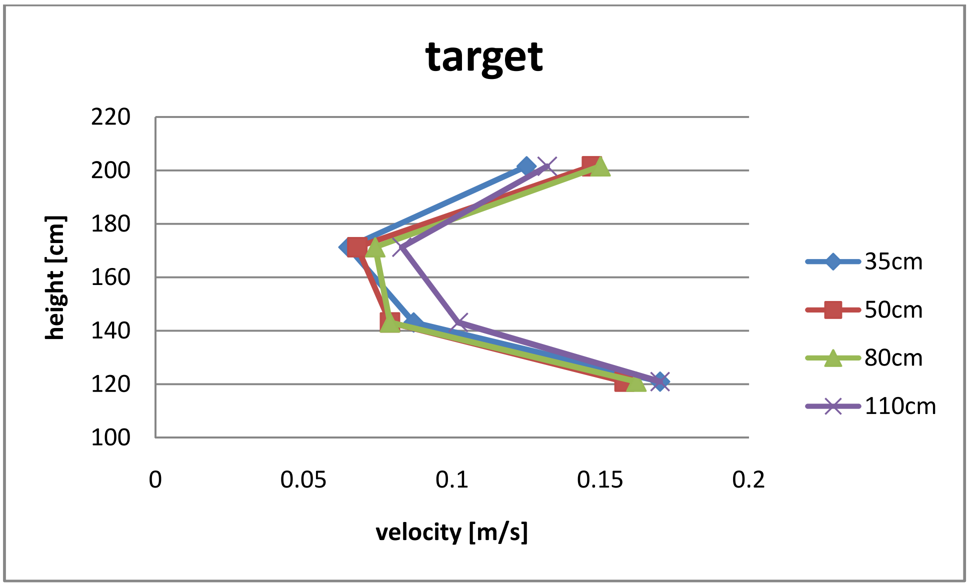


Figure 4.32 Velocity gradient by the target manikin

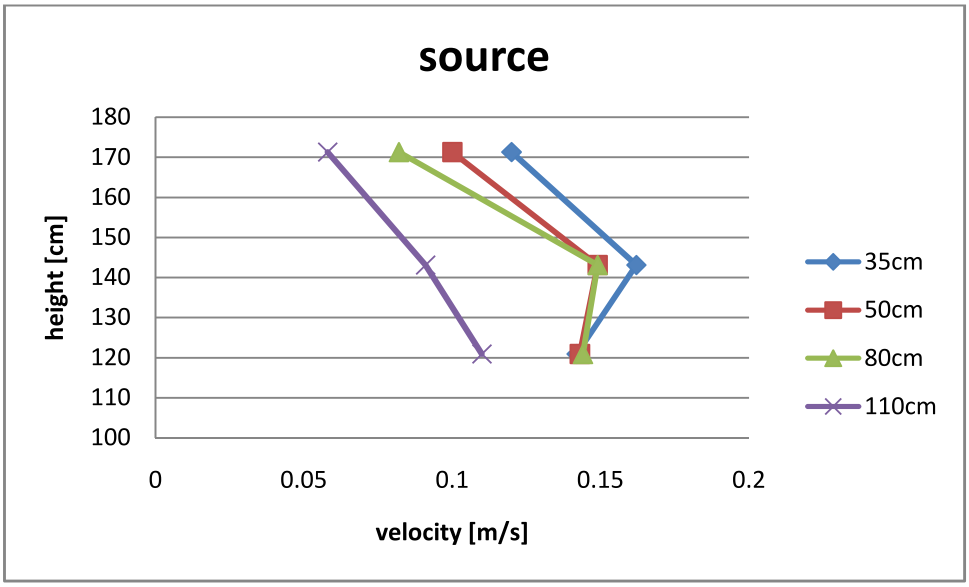


Figure 4.33 Velocity gradient by the source manikin

Cross

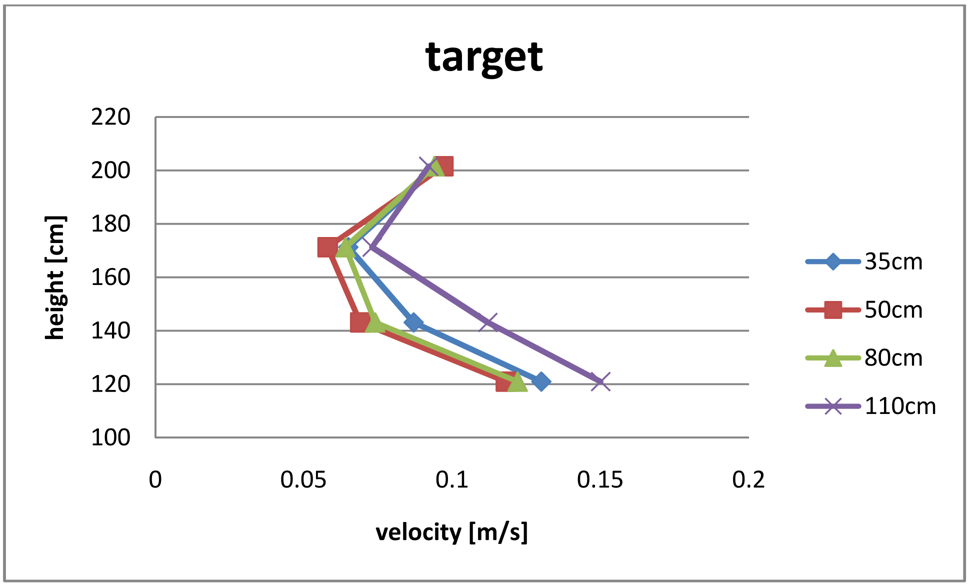


Figure 4.34 Velocity gradient by the target manikin

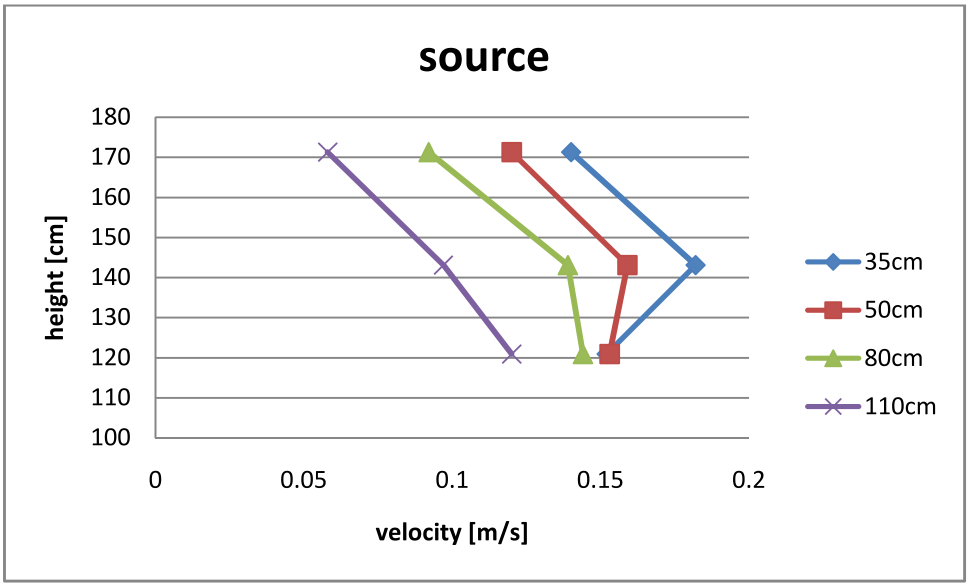


Figure 4.35 Velocity gradient by the source manikin

4.3.1 Temperature gradients by the manikins fronts

Temperature is measured next to the source and target manikins. Ten thermocouples are used and placed as it is seen in figure 3.8. Results are similar for all cases. It means that positions of manikins don't influence the distribution of temperature at short distance from them. Because of similarity of the results for different positions the graphs are described only once and the description corresponds also to the rest cases.

Face to face

In the figure 4.37 it's seen than the highest temperature is at the level of the chest. The reason of that is the geometry of the manikin. The chest is put forward relative to the rest of manikin's body. Hence when all of the thermocouples are placed in vertical line the one at the level of the chest is the closest to the hot surface of manikin. Furthermore it might be noticed that increasing the distance between manikins the temperature at the point located 200 cm above the floor also increases. The reason might be larger entraintment of the hot exhalation air.

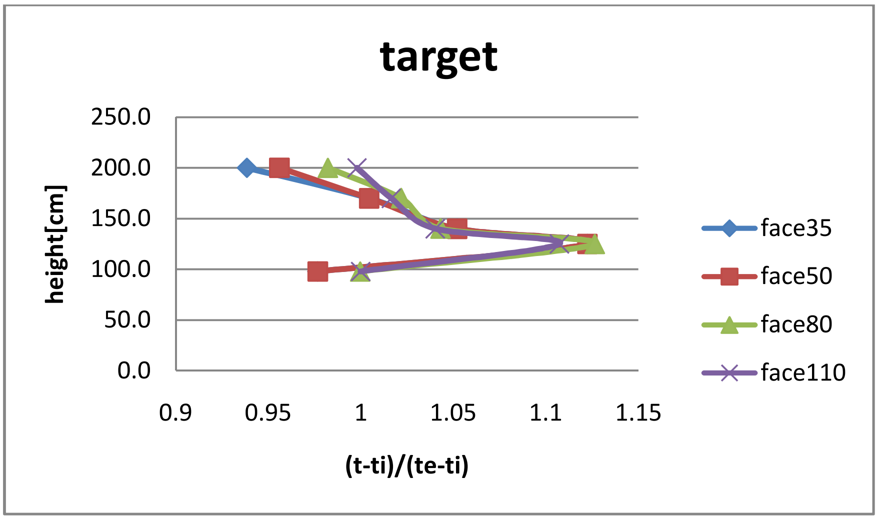


Figure 4.36 Temperature gradient by the target manikin

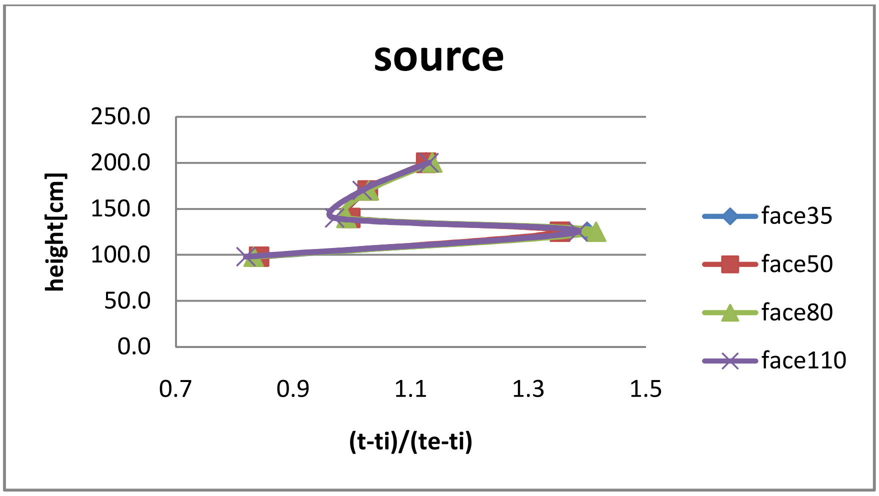


Figure 4.37 Temperature gradient by the source manikin

Face to back

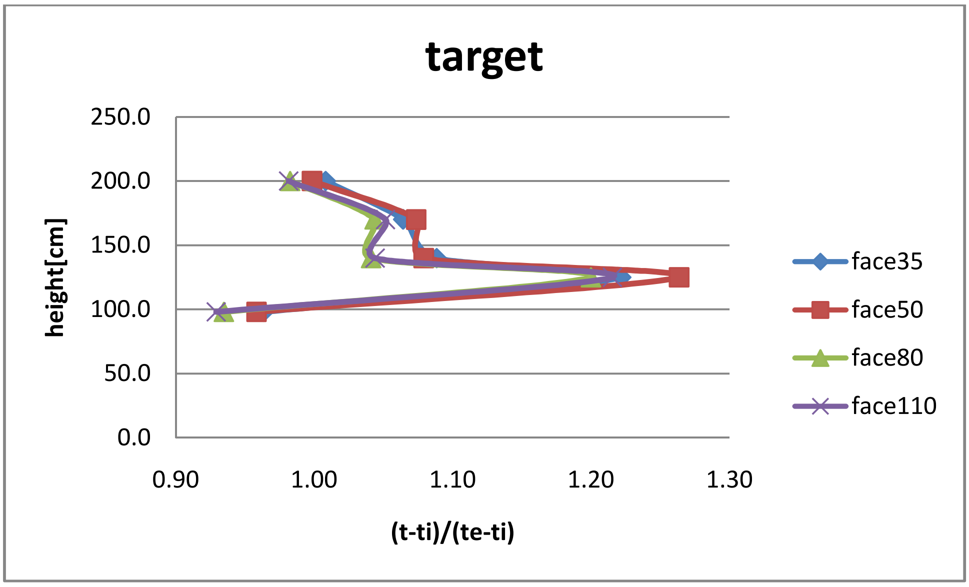


Figure 4.38 Temperature gradient by the target manikin

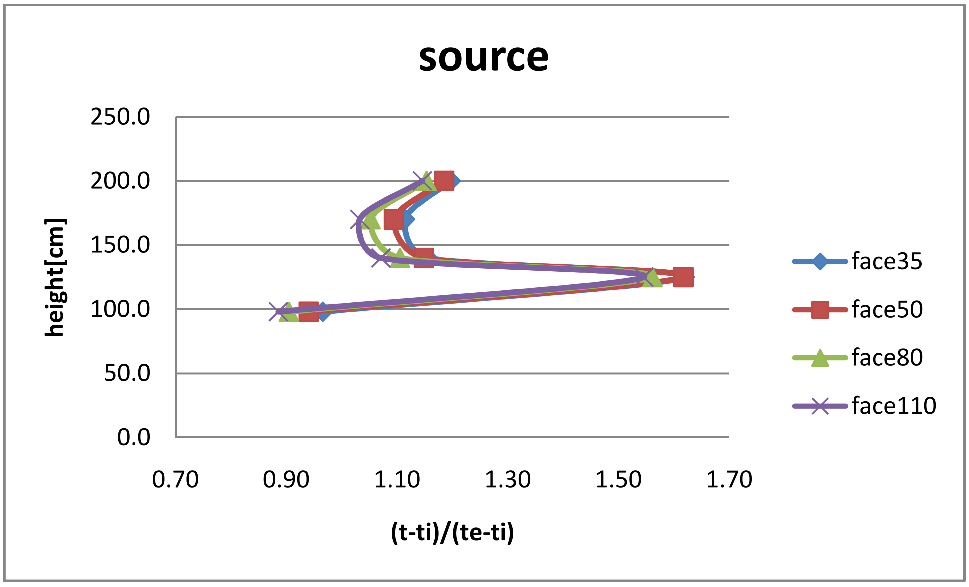


Figure 4.39 Temperature gradient by the source manikin

Cross

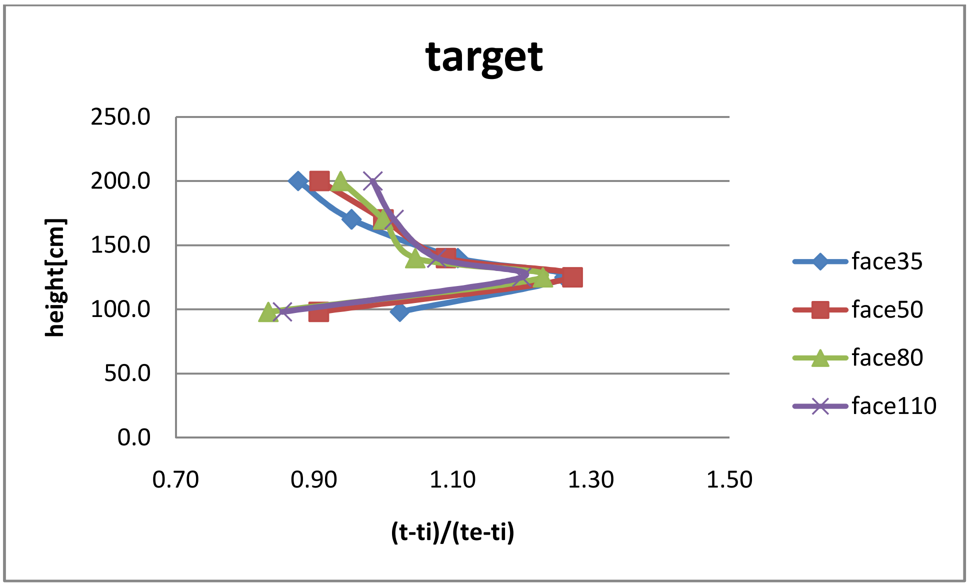


Figure 4.40 Temperature gradient by the target manikin

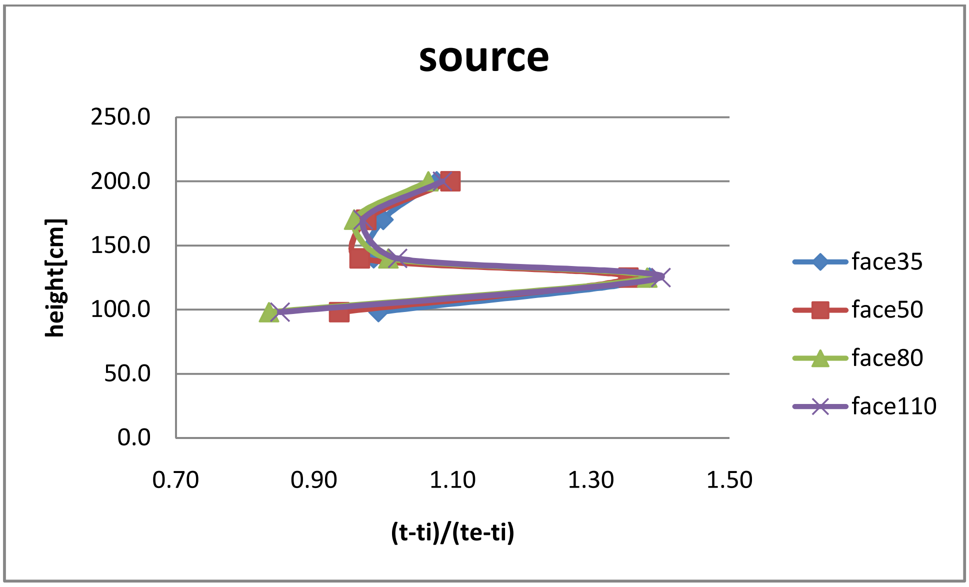


Figure 4.41 Temperature gradient by the source manikin

5. Results for one manikin

5.1 Thermal plume

In order to find out what is the level of protection against contaminants providing by thermal plume of manikin, measurements with one manikin are made.

Measurements are made in 3 series. Each time heating of the manikin is changed and is equal to 0W, 94W and 120W. Air change rate is kept constant. In order to maintain energy balance power of radiator is changed and is equal to: 488W for the manikin with heating 0W, 394W for the manikin with heating 94W and 368W for the manikin with heating 120W.

The manikin is placed in the middle of the room facing the radiator. Concentration is measured in 2 vertical lines as well as in the return openings. 3 points are placed along the manikin's body touching it: on the level of mouth (153cm), on the level of chest(125cm) and 93 cm above the floor. Three other points are placed on the stick, standing 50cm from a corner of manikin's shoulder, with angle between it and manikin's chest equal to 45°. Positions of them are seen in figure 5.1 and 5.2

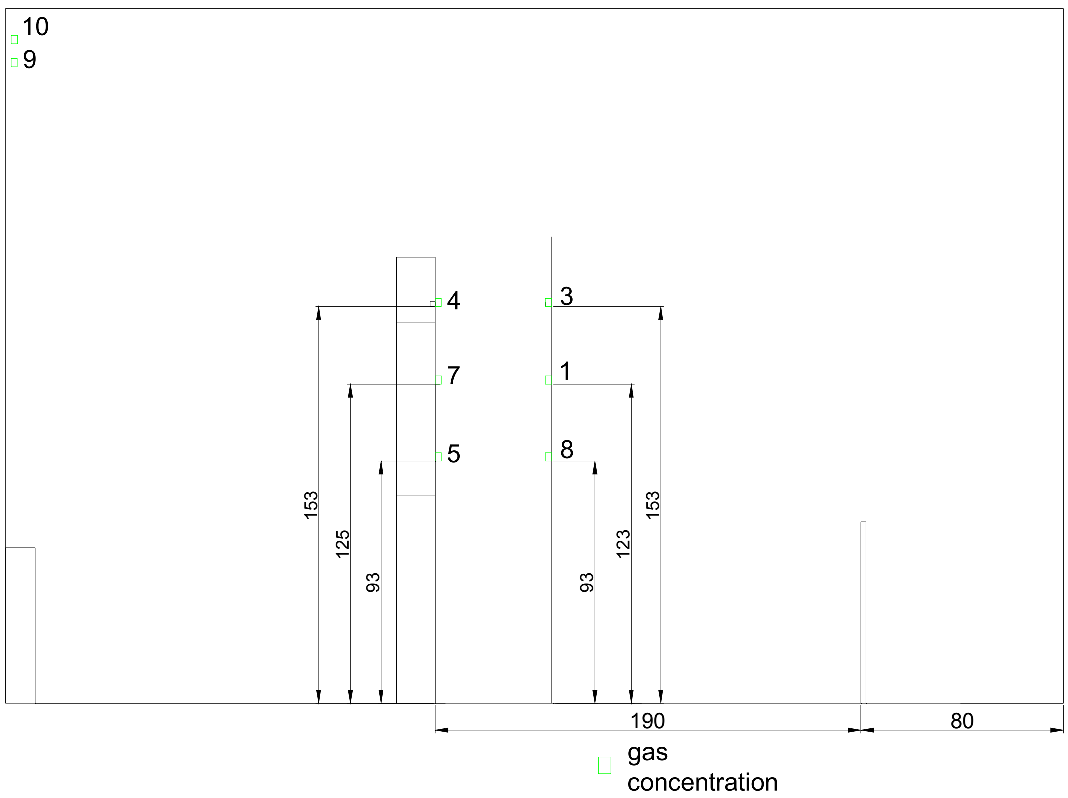


Figure 5.1 Positions of concentration measuring points (front view)

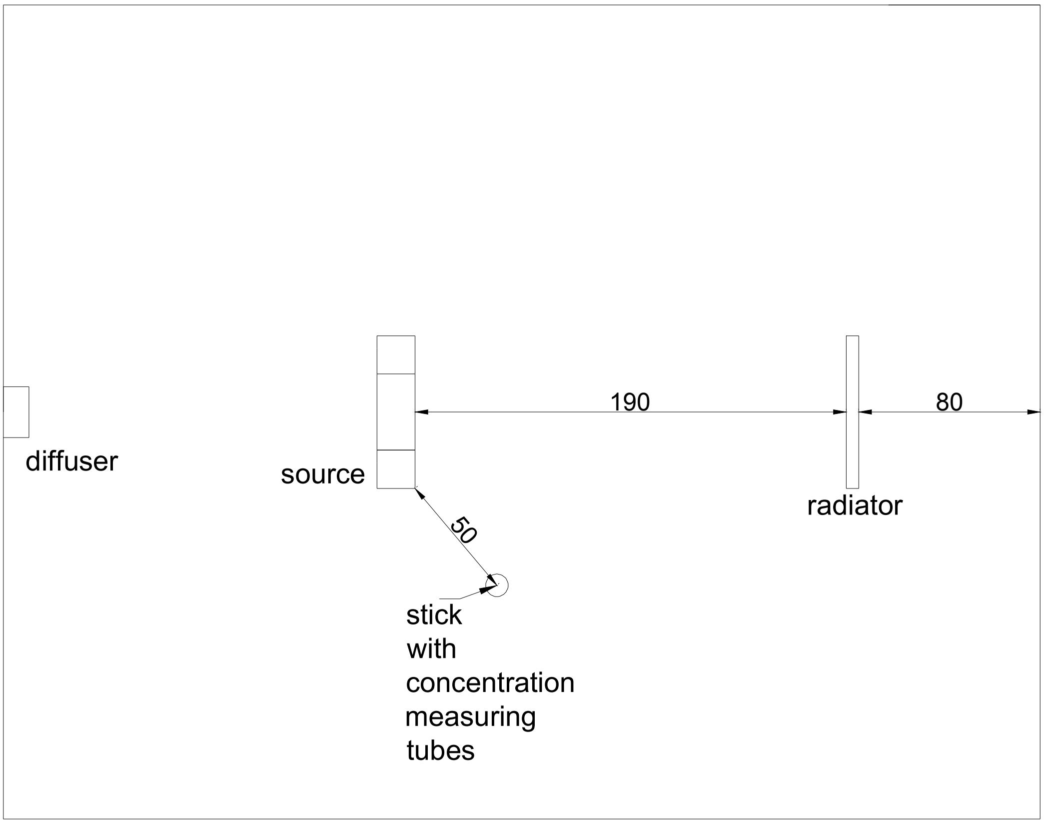


Figure 5.2 Positions of concentration measuring points (top view)

In figures 5.3, 5.4 and 5.5 there are presented results of tracer gas concentration close to manikin's body (Pman) and 50 cm from manikin (P50) for manikin's heating equal to 0W, 94W and 120W. In all cases it is seen that concentration level is very similar 93 cm above the floor. It increases with height but it is seen that it's higher on the stick than close to manikin's body. It indicates that thermal plume of the manikin gives the protection against contaminants.

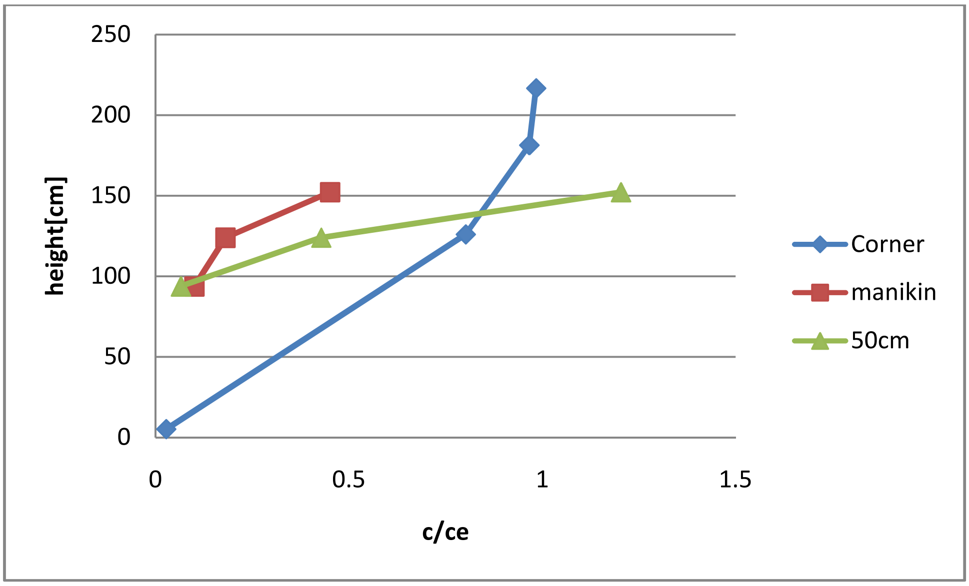


Figure 5.3 Results of concentration for case 0 W

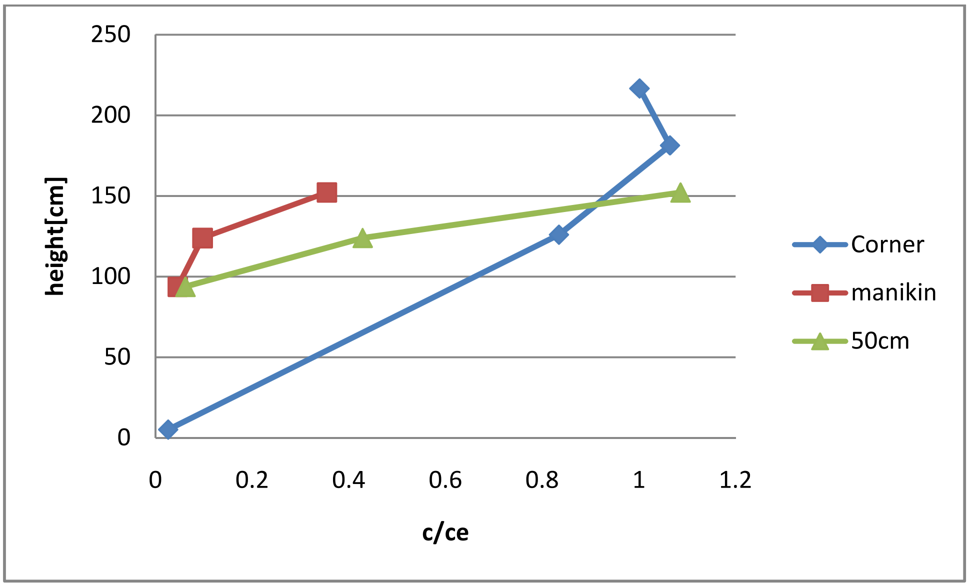


Figure 5.4 Results of concentration for case 94W

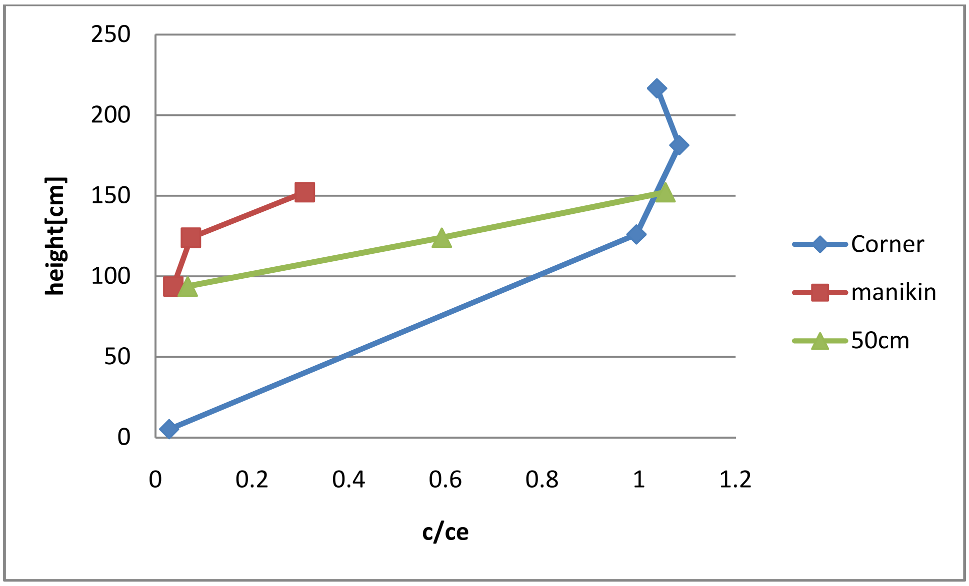


Figure 5.5 Results of concentration for case 120W

In figure 5.6 it's seen that concentration level is very similar in case 94W and 120W. When there is no heating from manikin concentration level is almost twice smaller, which also confirms protective function of thermal plume.

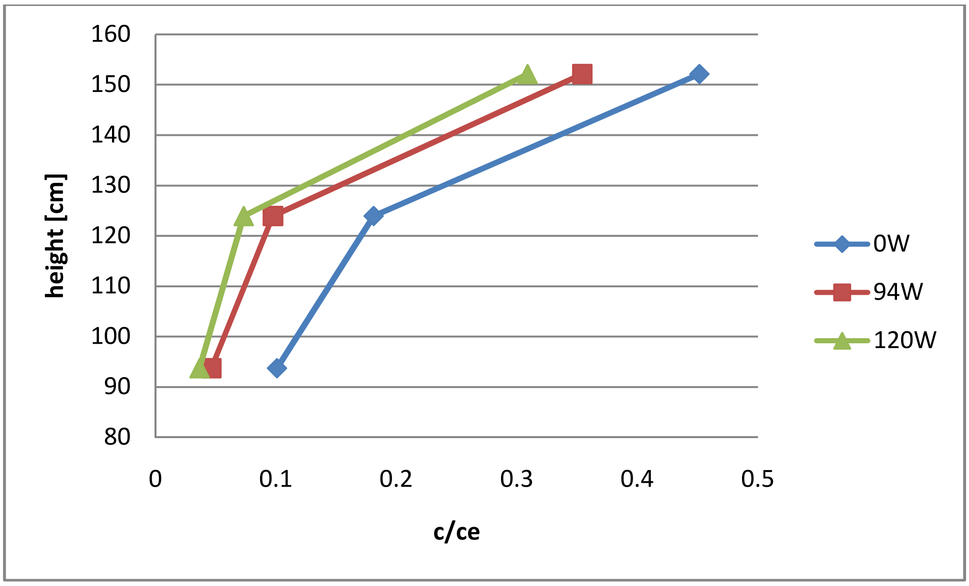
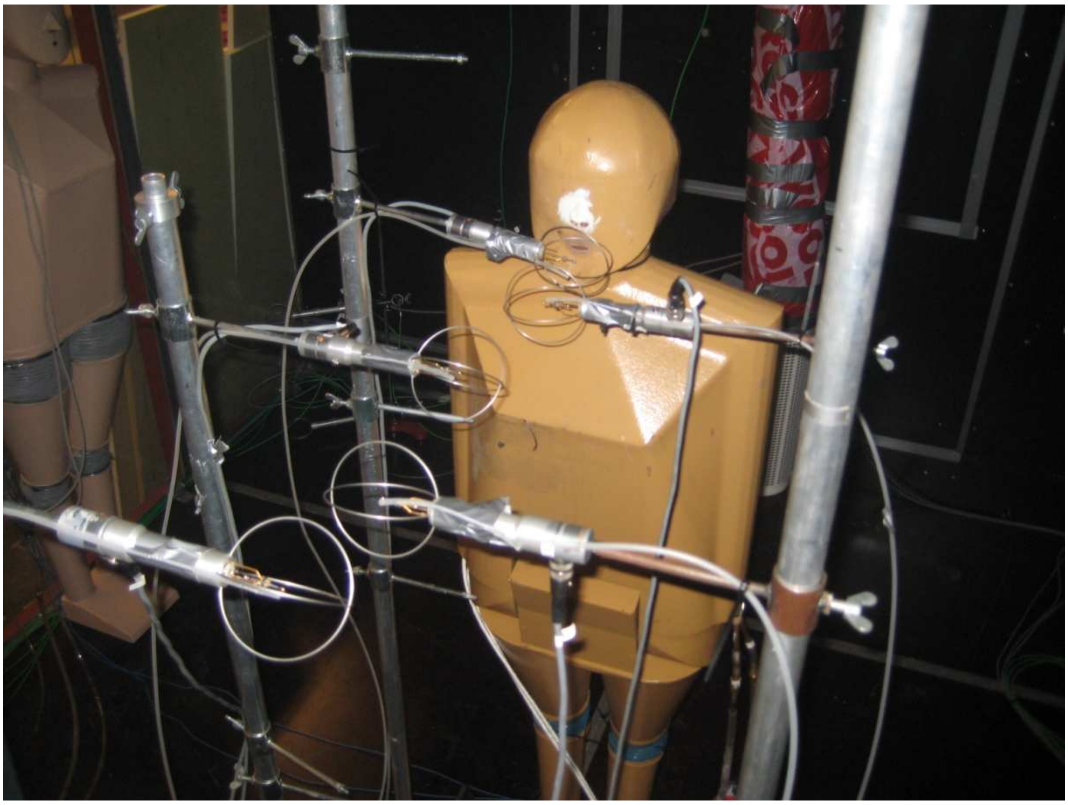


Figure 5.6 Results of concentration close to manikin's body

5.2 Exhalation jet

Investigation of exhalation jet is made. Air velocity and tracer gas concentration is measured. In order to find the trajectory of the jet smoke visualization is conducted with flow testers (see figure A.4.2). Anemometers and concentration measuring tubes are placed at the points with the highest velocities, which indicate the middle of the exhalation jet. The photo from experiment is given in figure 5.7 Positions of concentration measuring points are given in the figure 5.8



5.7 The photo of positions of anemometers and tracer gas measuring tubes

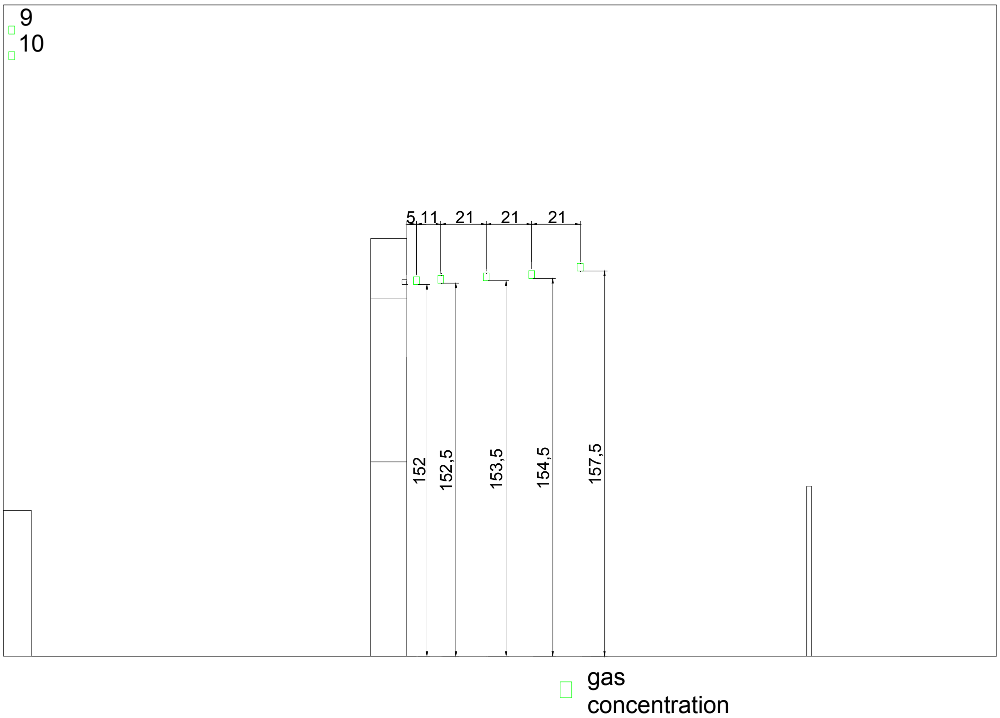


Figure 5.8 Positions of concentration measuring points

Dimensionless concentration in the exhalation jet at distance between 5 and 76 cm is calculated and given in figure 5.9. It is seen that concentration level decreases with distance from the mouth as it is expected. The gradient between 5cm and 76cm is equal to 13. However the function of concentration decay is not a straight line. It can be noticed that concentration gradient is larger between 5 and 35 cm than between 35 and 76 cm. In first case it's equal to 10 when in another one it is equal to 3. The reason of this is that the exhaled air is much more diluted further than 35 cm from the mouth. However it is seen that concentration is very high in whole investigated zone.

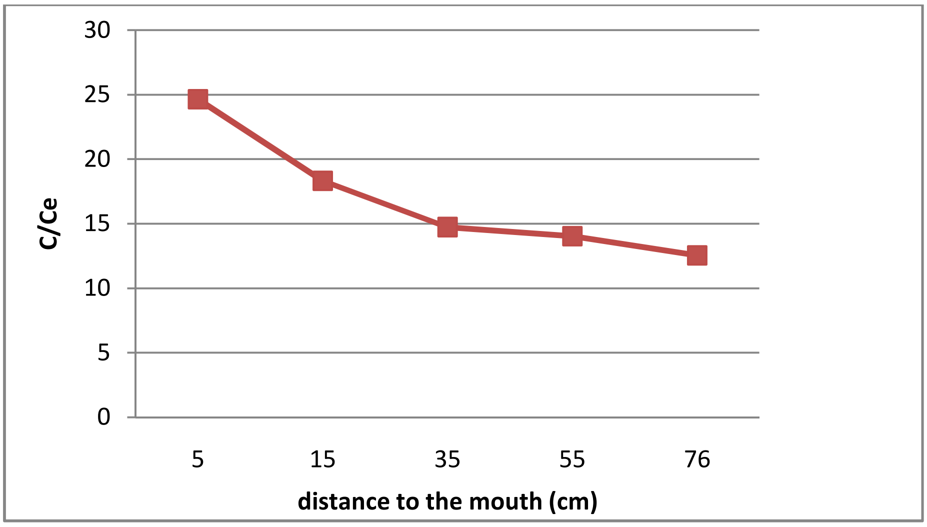


Figure 5.9 Concentration of tracer gas in exhalation jet

Positions of anemometers are given in figure 5.10

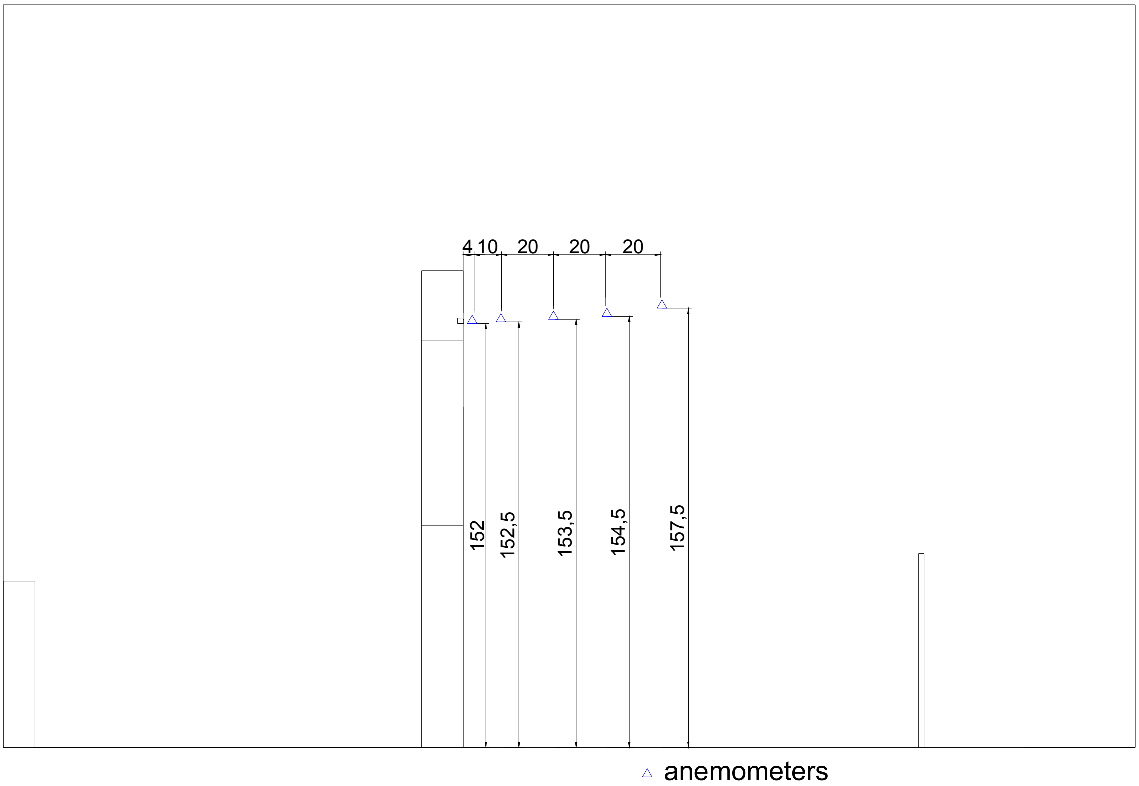


Figure 5.10 Positions of anemometers

An average velocity is measured at 5 points, which are seen in figure 5.10. A decay of the average air velocity in the jet leaving the opening can be calculated from following equation:

$$\frac{u_x}{u_o} \approx \frac{K_a}{\sqrt{2}} \frac{\sqrt{a_o}}{x} \qquad (1)$$

Where:

u_o - is the supply velocity

K_a - is a constant characterizing an opening

a_o - is the inlet effective supply area

x - is a distance between the opening and measured points (u_x)

In this case :

$a_o = 0,0001\ m^2$

$u_o = 1,85\ \frac{m}{s}$

After converting the equation it's possible to calculate K_a :

$$K_a \approx \sqrt{2}\,\frac{u_x \cdot x}{u_o \cdot \sqrt{a_o}} \qquad (2)$$

Calculation for all measured data are given in figure 5.11

x	0,04	0,14	0,34	0,54	0,74
u_x	1,03	0,58	0,33	0,22	0,16
u_x/u_o	0,56	0,31	0,18	0,12	0,09
$x/a_o^{1/2}$	4	14	34	54	74
K_a	5,15	6,21	8,58	9,08	9,05

Figure 5.11 Calculation results

For circular opening K_a should vary from 6 up to 10. Obtained results almost fulfill this requirement (5,15 - 9,05). The mean value of K_a equals 7,61. It means that K_a can be used to describe this opening.

In figure 5.12 there is given relation between u_x/u_o and $x/a_o^{\frac{1}{2}}$ on log-log graph and it is almost straight line. Hence velocity along the exhalation jet of breathing can be expressed as equation 1.

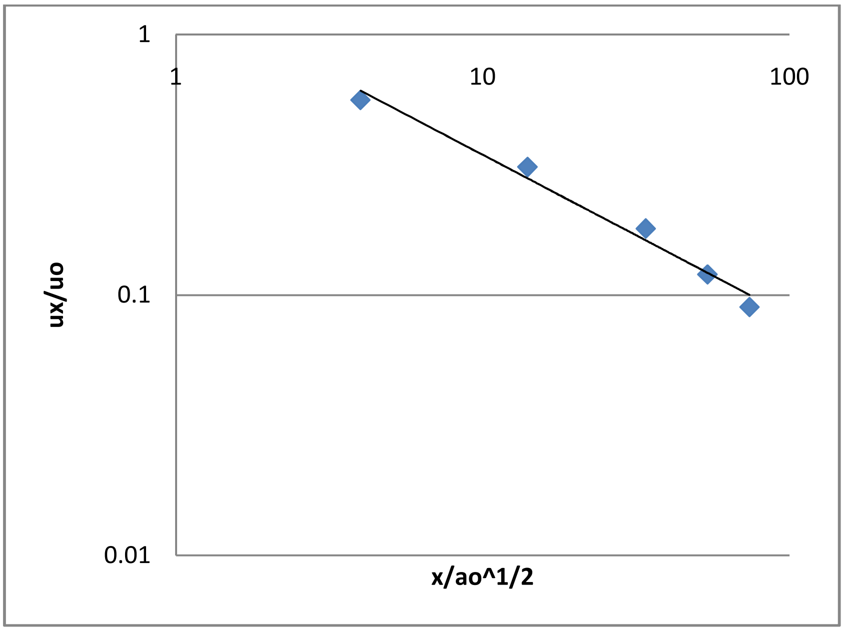


Figure 5.12 Relation between u_x/u_o and $x/a_o^{\frac{1}{2}}$

6. Problems encountered during measurements

6.1 Position of manikin

It is noticed that when manikin is in a straight position the surface of the mouth is not parallel to the floor. Therefore the exhalation jet is directed slightly upwards. An illustration of the situation is presented in figure 6.1

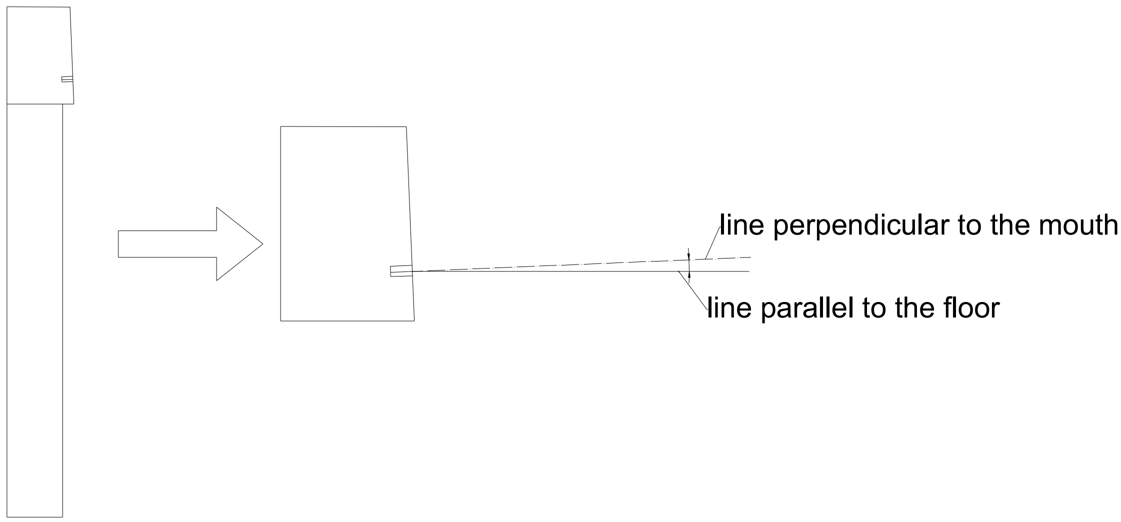


Figure 6.1 Position of manikin before change

To avoid the problem presented above it is decided to tilt the upper part of manikin. This way the surface of the mouth is parallel to the floor and exhalation jet has a right direction. It is seen in figure 6.2

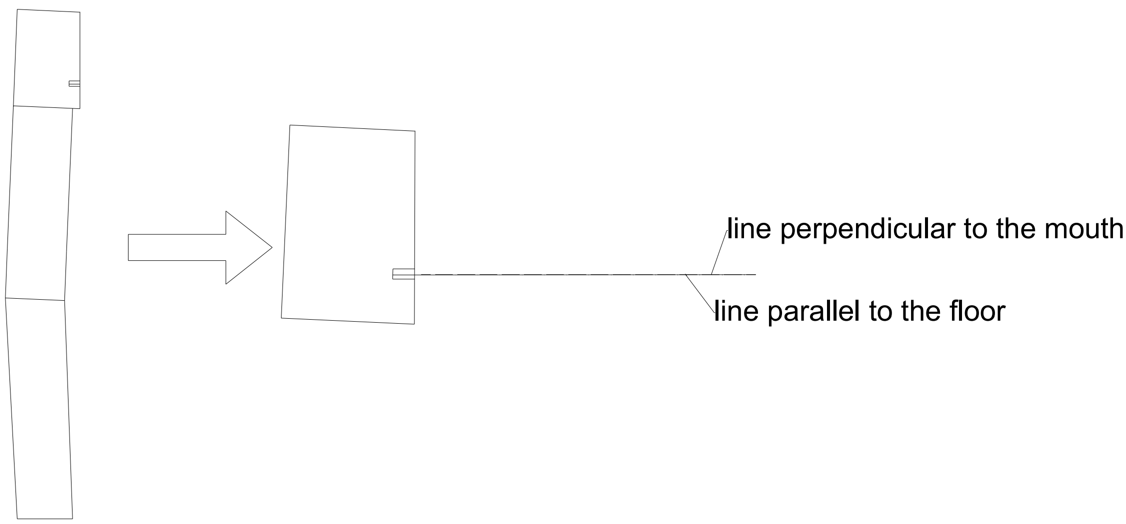
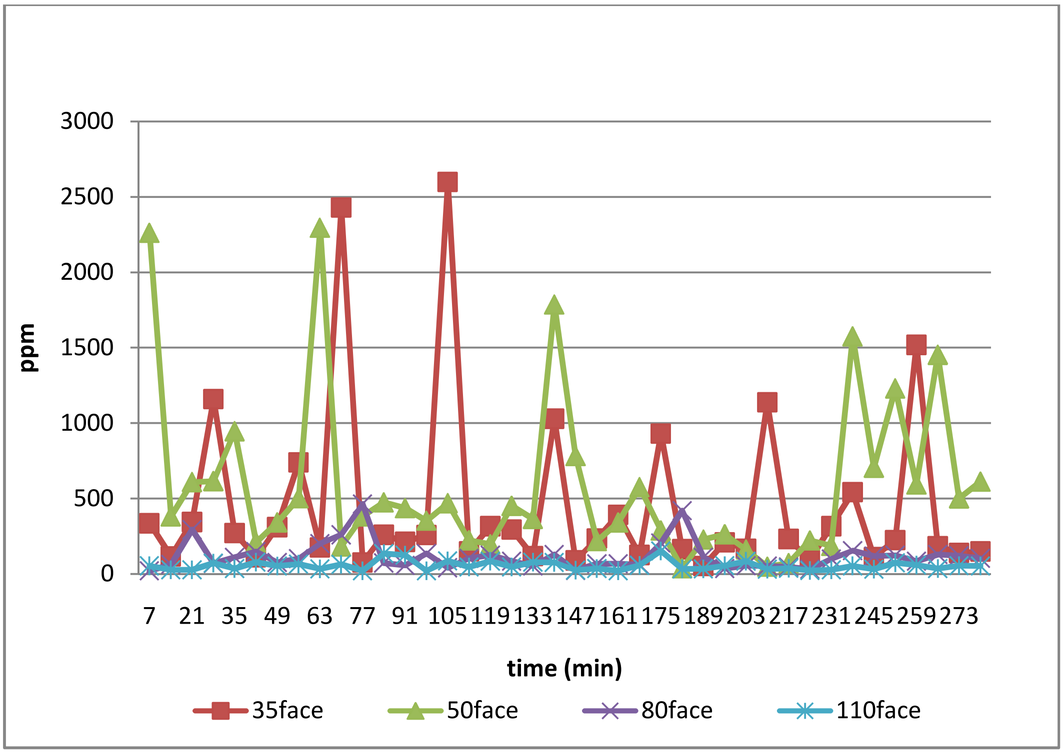


Figure 6.2 Position of manikin after change

6.2 Peaks of concentration

Looking at detailed results of tracer gas concentration it is noticed that sometimes very large values are obtained, what is seen in the example in figure 6.3. They appear because sometimes taking samples of the air by tracer measuring equipment is perfectly synchronized with exhalation of source manikin and inhalation of target manikin. In order to get reliable average results the time of one measurement is extend to 5 hours (the longest possible time of collecting data by Sampler and Doser)



6.3 Peaks of tracer gas concentration for inhalation of target manikin

6.3 Heat gains and heat loses

In order to keep steady states in the test room during measurements heat gains and heat loses have to be eliminated. It's done by calculating energy balance and monitoring laboratory temperature and if it's necessary adjusting it to be equal to average temperature in the room (more details about this in chapter 3.5)

7. CFD

Computational Fluid Dynamics is one of the branches of Fluid Dynamics. By means of numerical methods and algorithms it is capable of solving problems which involve fluid flows. Fundamental flow equations including continuity, three momentum, energy and transport equations are the basis of CFD. Solving them it's possible to obtain the prediction of air velocity, temperature, pressure, contaminant distribution and others.

Two programs are used to make a simulation. Those are Rhino and Ansys CFX. Rhino is a program, thanks to which it is possible to make 3D model. Ansys CFX consists of 4 parts: Ansys Workbench, CFX-Pre, CFX-Solver and CFX-Post.

Ansys Workbench - is software for generating a mesh. 3 D model is divided into small cells. The number of cells has an influence on accuracy of results.

CFX – Pre - is a tool for setting boundary conditions as well as choosing turbulence model

CFX – Solver - is an application that uses numerical methods and algorithms to solve conservation equations

CFX – Solver – is a final stage of simulation. It allows to post-process the results. Furthermore it enables mesh quality examination.

7.1 Turbulence model

The k – ε model is chosen since it is considered to be simple model and in the same time giving good results. In this model transport equations are solved for the turbulent kinetic energy k , and its dissipation ε.

7.2 Boundary conditions

In order to be able to compare results from simulations with results from measurements it's very important to create in CFD conditions which are similar to measurements. However because of restrictions in computer power and time some simplifications has to be made and they are described below.

7.2.1 The test room

3 D model of the test room is created with dimensions 410cm x 320cm x 270cm.

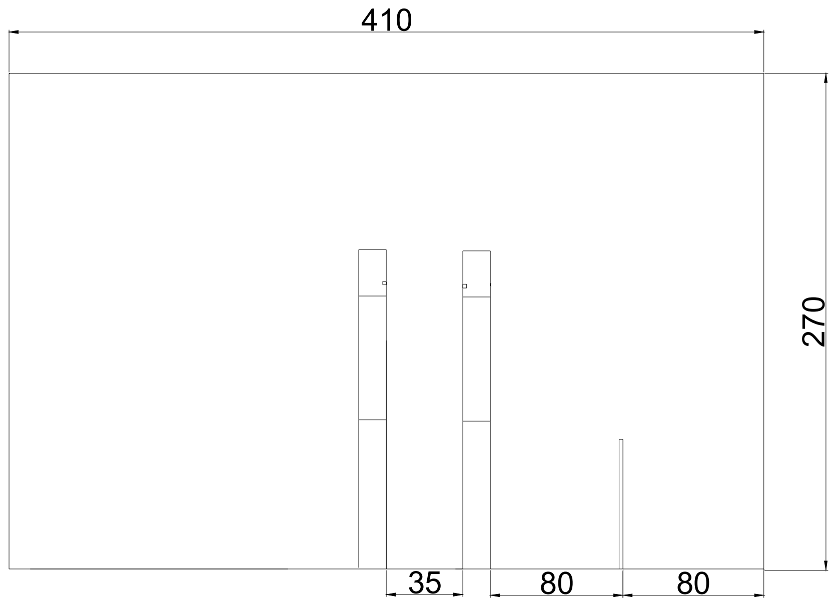


Figure 7.1 Front view of the model used in CFD

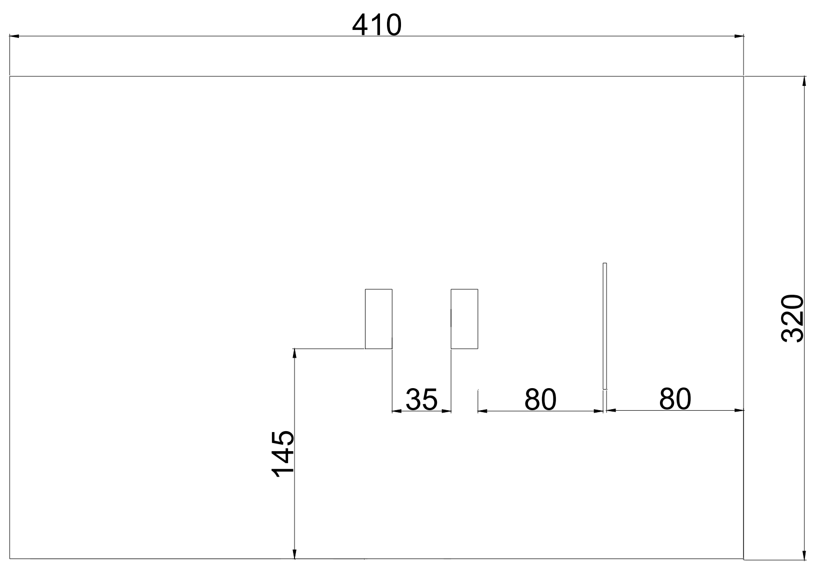


Figure 7.2 Top view of the model used in CFD

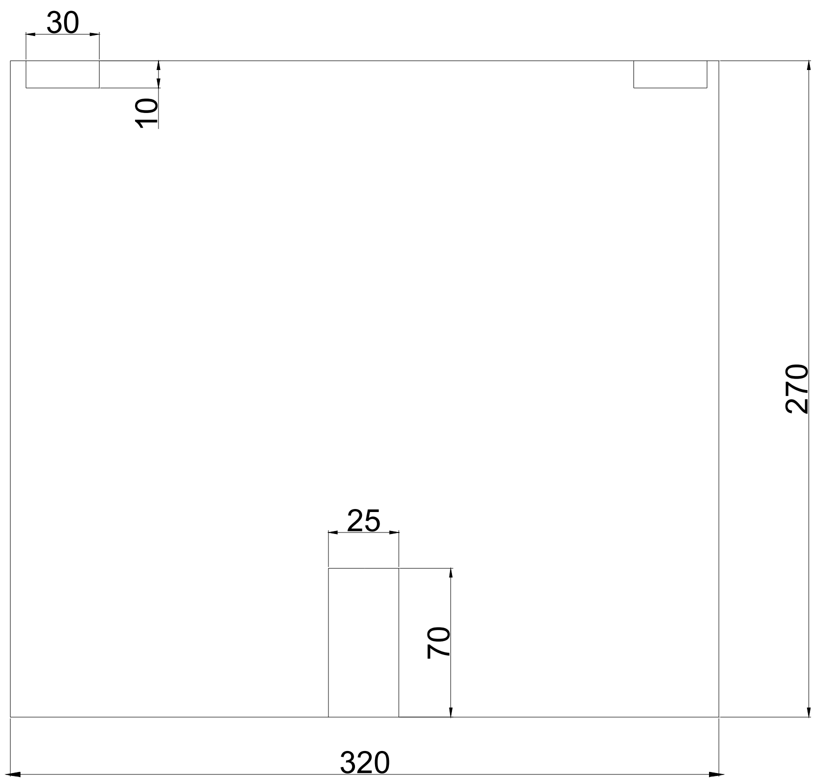


Figure 7.2 Cross view of the wall with diffuser and return openings

7.2.2 Diffuser

In order to find out how to simulate a diffuser in CFD velocity profile from measurements is compared with velocity profiles from CFD simulations with different shapes of the diffuser.

Air velocity is measured at 5 points at distance 60, 80, 100, 120 and 140 cm from the diffuser. All anemometers are placed on the horizontal line 3 cm above the floor. Monitor points in CFD are located in the same places. A schema is given in figure 7.2.

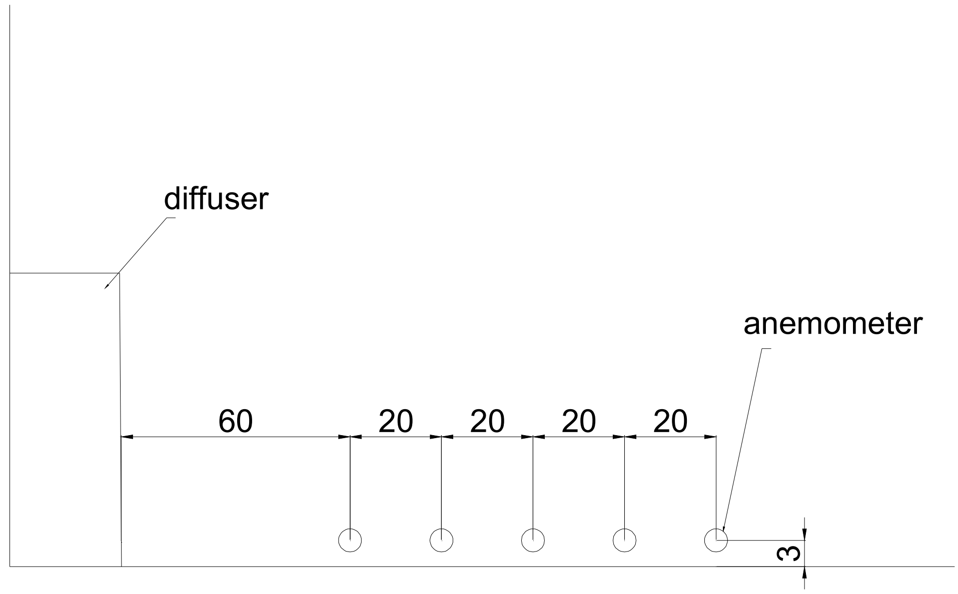


Figure 7.2 Sketch of location of anemometer in measurements and monitor points in CFD

Three different types of the diffuser are taken into consideration. Sketches of them are presented in figure 7.3.

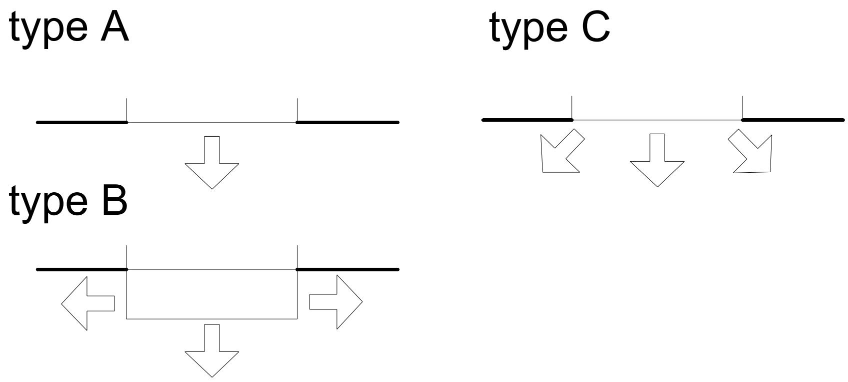


Figure 7.3 Sketches of different diffusers investigated in CFD

In figure 7.4 it is seen that in case of measurements the highest velocity is 100 cm from the diffuser. That indicates that at this point cold air from the diffuser falls down because of gravity forces. This phenomena is not noticed in CFD. Investigation shows that shape of diffuser doesn't have huge influence on the results. Therefore it's decided to use the simplest diffuser, type A.

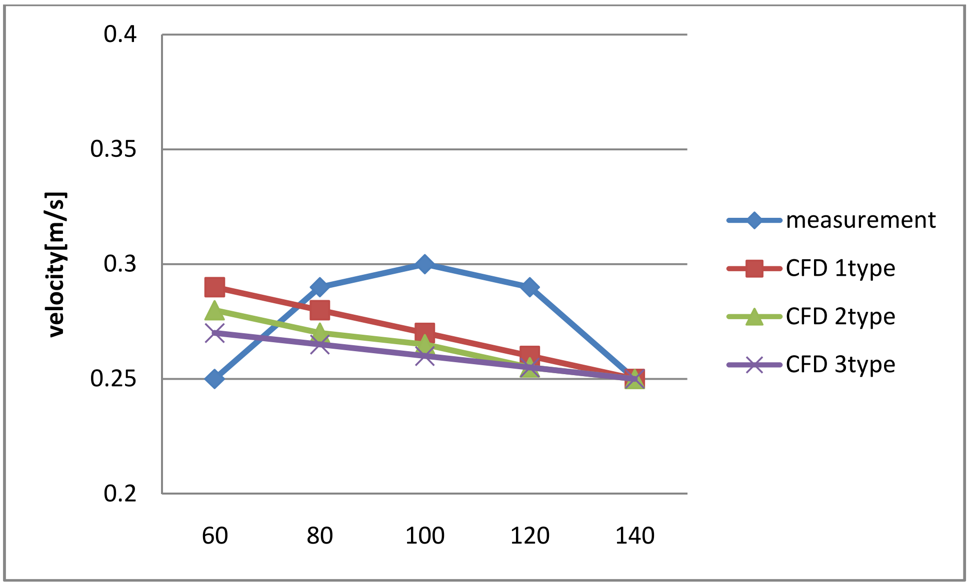


Figure 7.4 Velocity profile

The surface area of the diffuser is calculated from the equation :

$V = v \cdot A$

Where V is an airflow from the diffuser [m^3/s]

v is a velocity of air coming out of the diffuser [m/s]

A is a surface of the diffuser

$V = 0{,}056$ [m^3/s]

$v = 0{,}3$ [m/s]

Hence $A = 0{,}188$ [m^2]

Assumed dimensions of the diffuser : 0,7 m x 0,25m

7.2.3 Manikins

The model of the manikin is simplified in order to avoid convergence problems during simulations. Surface of the manikin's body equals to 1,62 m^2.

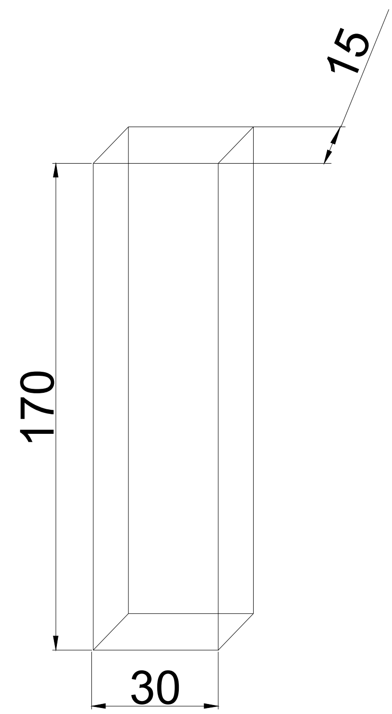


Figure 7.5 Model of manikin used in CFD

Mouth of the manikin is also simplified. It has rectangle shape with dimensions of 20x5 mm.

7.2.4 Heat load

Each of the manikins release 94 W, which corresponds to 29 W/m^2.

The radiator release 300 W, which corresponds to 333 W/m^2.

Given values are an half of the values used in the measurements since in CFD radiation is not taken into consideration.

7.2.5 Airflows from the diffuser and from the mouth

Airflow from the diffuser is the same as the one used in measurement and equals 56 [l/s] .

Airflow from the mouth is steady and consists only of exhalation because of limitations of the program. In order to get the same velocity as in the measurements the airflow has to be doubled comparing to measurements. Therefore it equals 22 [l/s] .

Furthermore it is assumed that only source manikin is breathing. In case of breathing of two manikins there would be a crash of exhalation jets due to steady state airflows. This would cause that results of concentration would not correspond to results from measurements.

7.3 Grid independence

"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]

In order to find the best grid 3 simulations with different numbers of cells are conducted. Temperature gradient by the target manikin is taken into consideration.

The grid consisted of 428 552 cells is the appropriate, because increasing number of cells does not have significant impact on improving the accuracy of results but only extends the time of simulation.

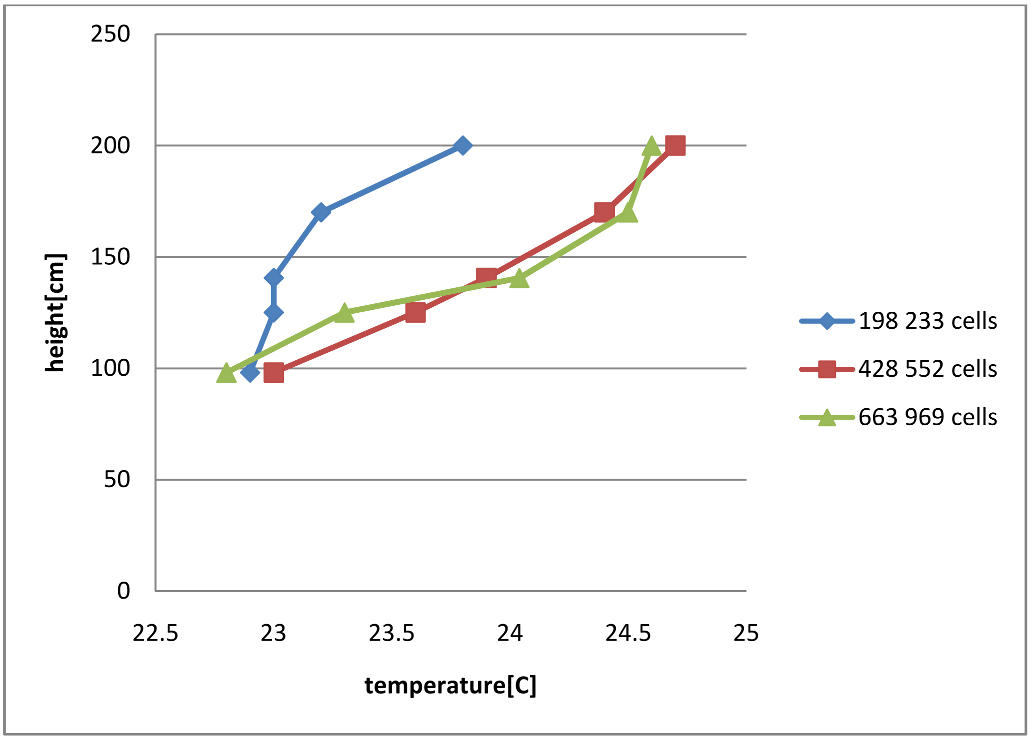


Figure 7.6 Temperature gradient by the target manikin for 3 grids with different number of cells

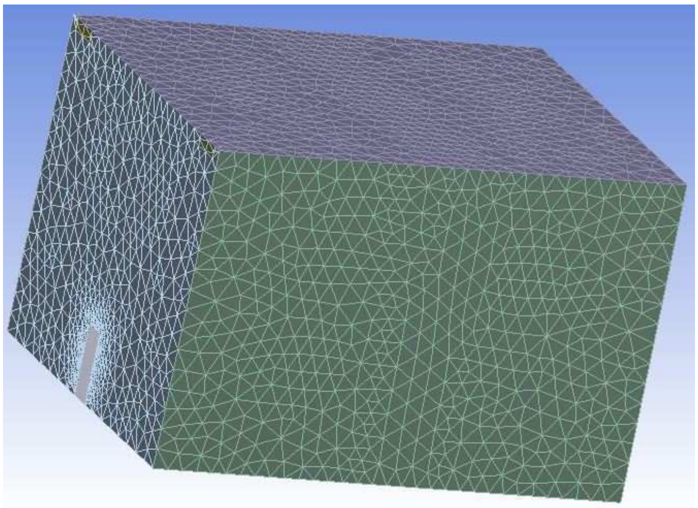


Figure 7.7 Grid used in simulations

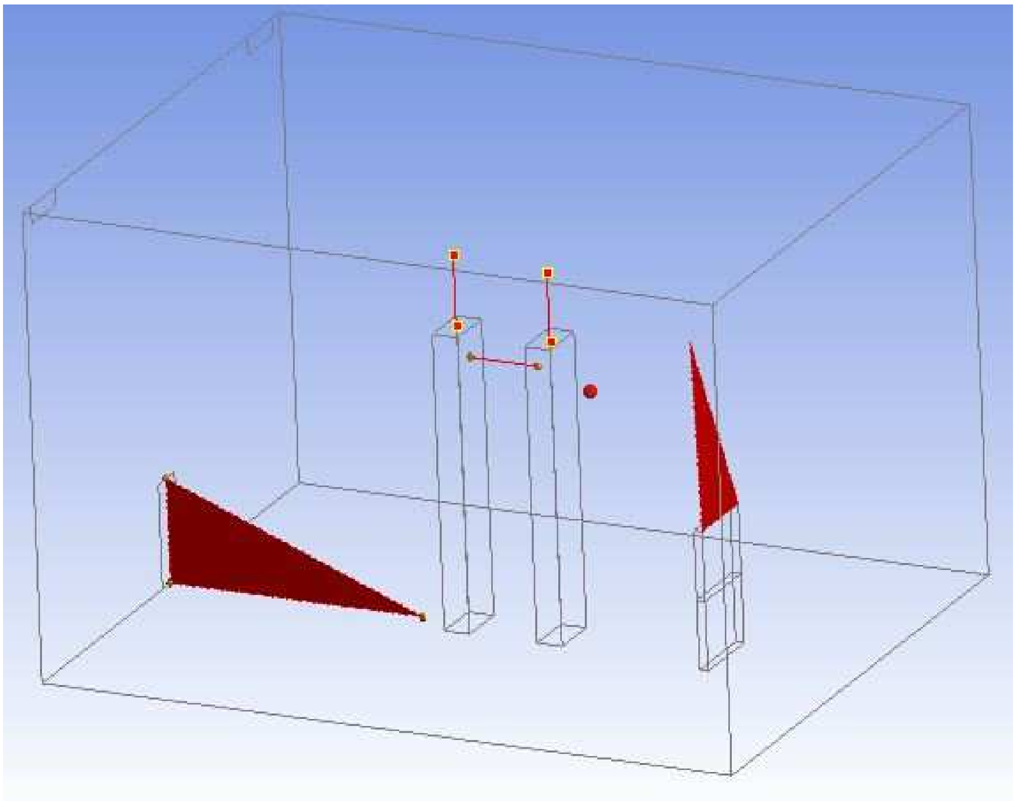


Figure 7.8 Places with finer grid

7.4 Results

7.4.1 Temperature distribution

In figure 7.9 it is seen temperature distribution in the room. It might be noticed the stratification of the temperature what is typical for displacement ventilation. Vertical temperature gradient is larger than in measurements and is equal to 4,5 °C.

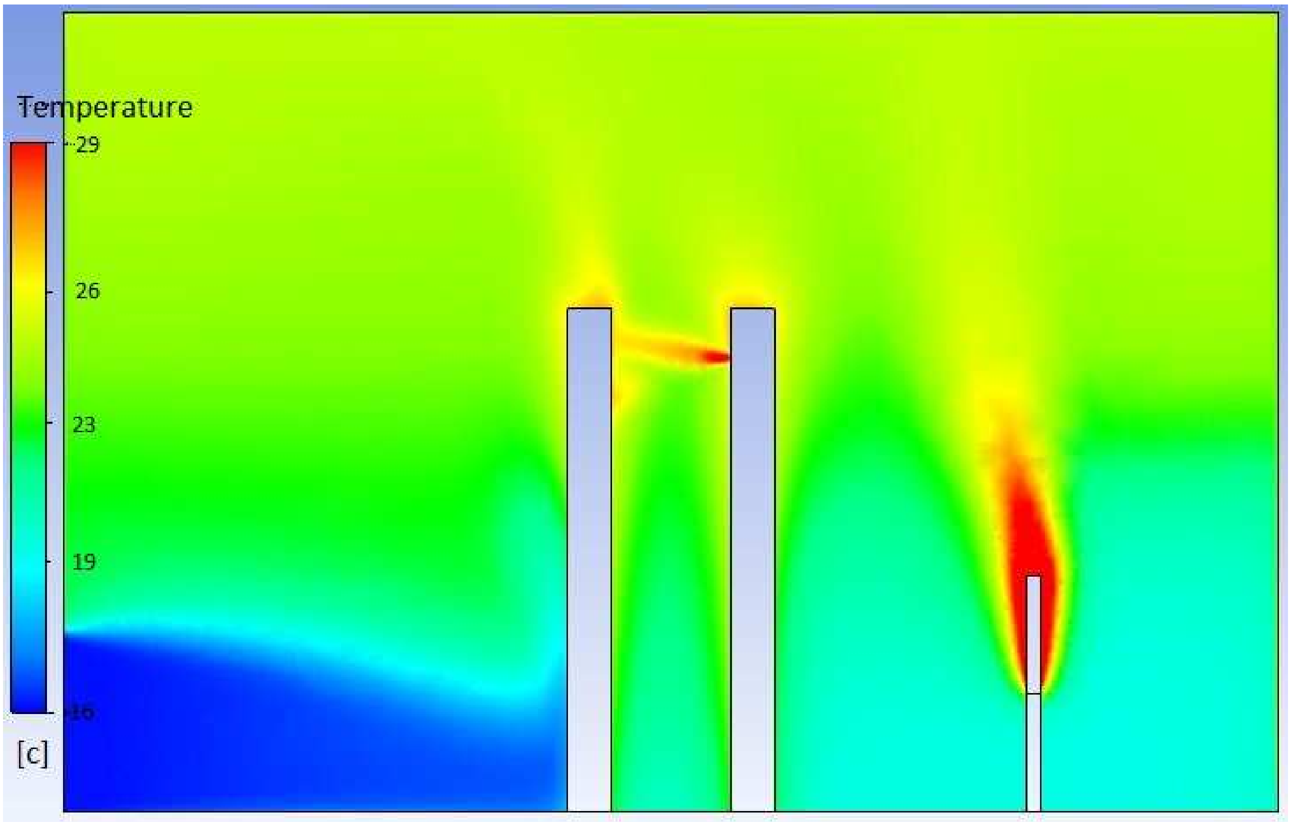


Figure 7.9 Temperature distribution in the room

7.4.2 Tracer gas concentration

Distribution of tracer gas in CFD does not agree with measurements. The reason of that might be simplifications assumed in CFD such as breathing of only one manikin or simplified geometry of stuff in the room. However values of exposures at the level of manikins mouth and chest are very similar to the measurements results.

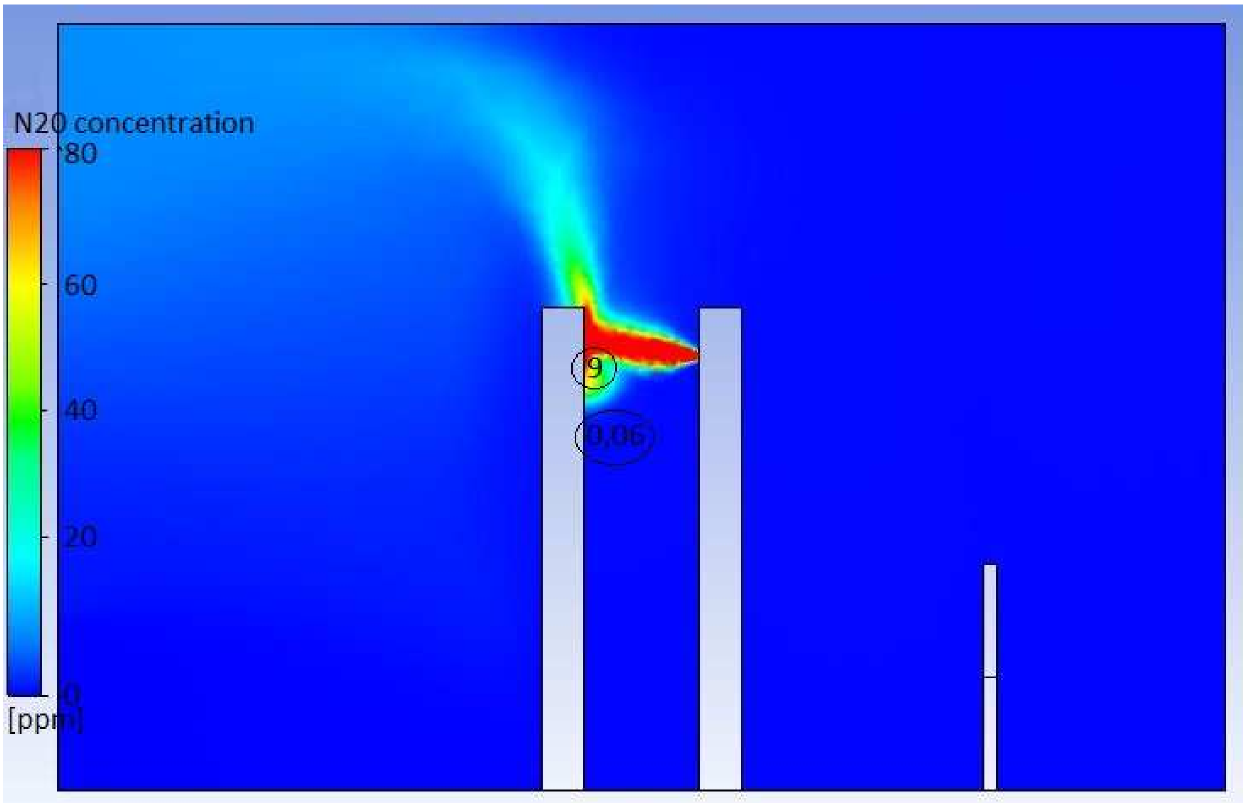


Figure 7.10 Tracer gas concentration in the room

	chest	mouth
measurements	0,05	12
cfd	0,06	9

Figure 7.11 Comparison of exposure[-] for case “face to face 35cm” between CFD and measurements results

7.4.3 Velocity distribution

In figure 7.12 it is seen velocity distribution in the room.

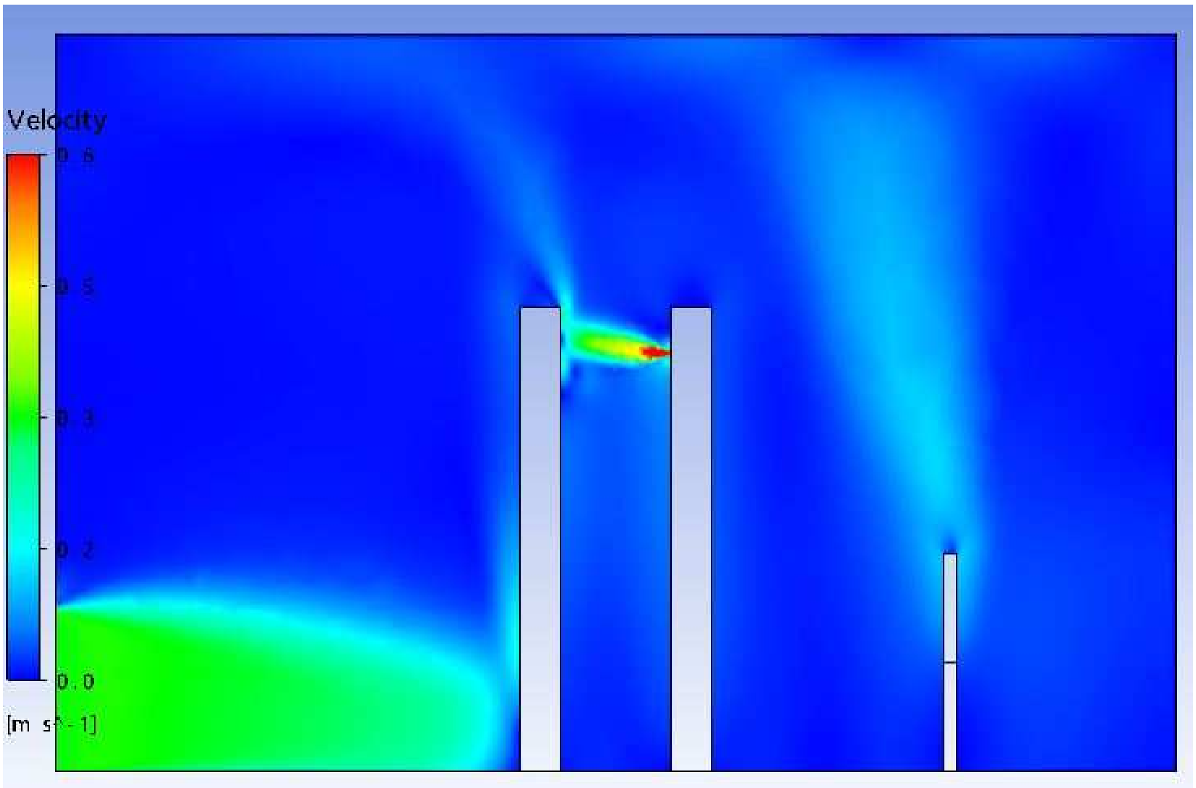


Figure 7.12 Velocity distribution in the room

Comparing velocities results (CFD and measurements) by the target manikin's front it is seen that at points at height of 170cm and 200cm results are very similar. The difference might be noticed at lower heights.

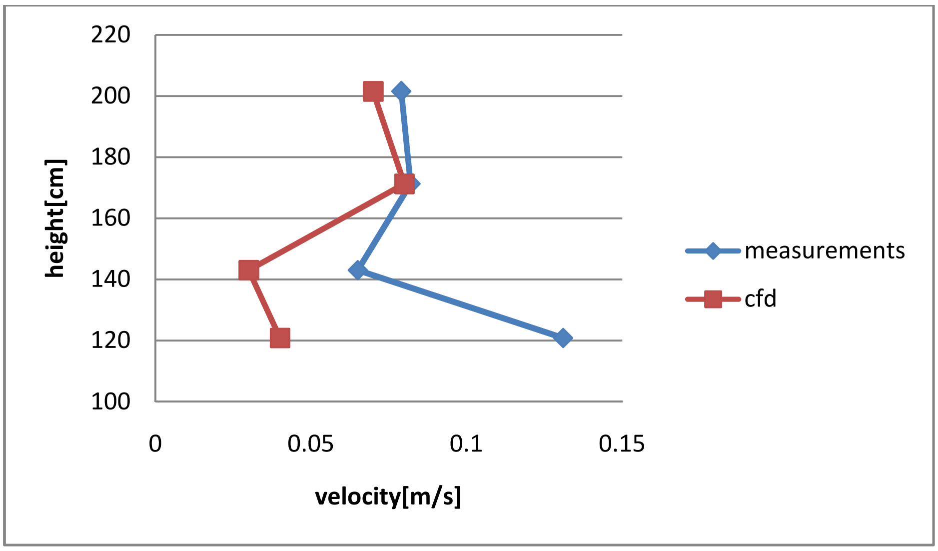


Figure 7.13 Comparison of velocities by the target manikin's front between measurements and CFD results

8. Conclusions

On the basis of the project following conclusions are drawn:

1. There are 2 phenomena around human body which have influence on the surroundings, those are thermal plume and exhalation jet.
2. Thermal plume is kind of protection against cross infection. Concentration level is almost twice lower when heating of manikin is turned on comparing to case without heating.
3. Exhalation jet is slightly directed upwards, because of higher temperature of exhaled air than ambient air.
4. Concentration decay is 3 times larger at distance between 5 and 35cm from the mouth than between 35 and 76cm from the source manikin's mouth.
5. Distance between manikins has an influence on concentration gradient in the corner of the room. Closer the manikins are to each other higher the concentration in the corner is obtained.
6. At height of 170 cm above the floor the highest concentration is just above target manikins head because that point is directly exposed to exhalation jet, the smallest concentration is in the corner of the room.
7. At height of 125 cm above the floor concentration level in the corner is higher than the one measured at manikins chests, because of protective function of thermal plumes around manikins bodies.
8. Level of tracer gas concentration in the air inhaled by target manikin depends significantly on position of both manikins. Distance between manikins is important only in case "face to face" and "cross".
9. Concentration level at the chest of target manikin is almost 100 times higher in case when source manikin is sitting than when both are standing.
10. CFD simulations are a useful addition to the measurements but they shouldn't be used as a single design tool.

APENDIX

A. Equipment and calibration

A.1 Temperature

A.1.1 Equipment

In order to measure temperature thermocouples are used. Thermocouples are pairs of dissimilar metal wires, which are joined at least at one end. When the junction of two metals is heated or cooled a voltage is produced that can be correlated back to temperature.

There are many types of thermocouples. They are made out off different kinds of metals. Although the most common are K, J, T, E.

In the measurements only thermocouples type K (Chrome (+) – Alumel(-)) are used (figure A.1.1). This type of thermocouple is most commonly used as it is inexpensive and available in a range of -200°C to 1350°C.

Figure A.1.1: K-type thermocouple

<u>*Grant SQ1600 Squirrel Meter/Logger*</u>

All thermocouples are connected to Grant Squirrel SQ1600 (figure A.1.2), which gathers data and transfer them later on into a PC.

Figure A.1.2: Grant Squirrel SQ 1000

Figure A.1.3: Screen shot from data loger

In the experiment temperature is measured by 37 thermocouples

A.1.2 Calibration

Thermocouples are calibrated using ISOCAL 6 VENUS2140B+ and Precision Thermometer F200.

Figure A.1.4: ISOCAL 6 VENUS2140B+ Figure A.1.5: Precision Thermometer F200

Calibration is made for three temperatures: 10°C, 25°C and 40°C. An idea is to get relation between true temperature shown by the precision thermometer and the one measured by Squirrel SQ1600 in ISOCAL 6. An example of calibration curve is shown in figure A.1.6 The rest of calibration files are attached on cd.

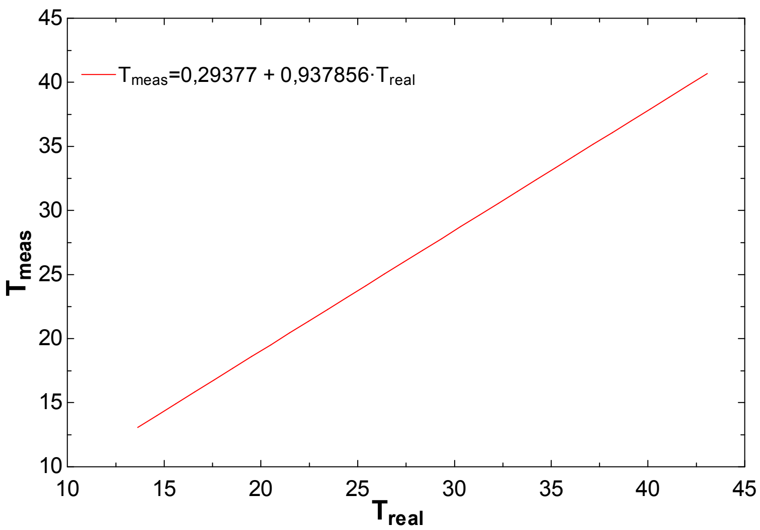


Figure A.1.6 Calibration curve for thermocouple no. 3

A.2 Velocity

A.2.1 Equipment

Velocity measurement are conducted by means of 7 DANTEC 54R10 hot sphere anemometers, shown in figure A.2.1

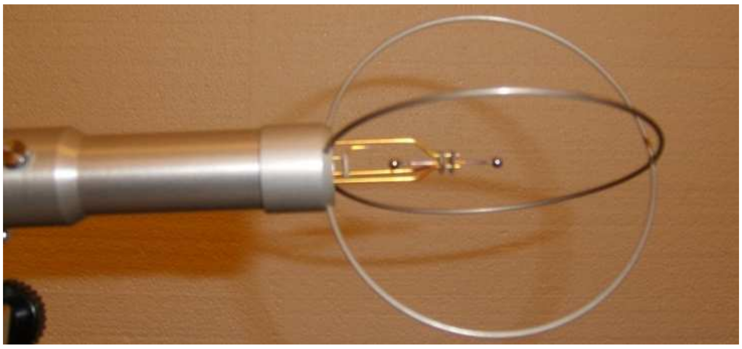


Figure A.2.1 DANTEC 54R10 hot sphere anemometer

Dantec Multichannel Flow Analyser 54R10

All anemometers are connected to Dantec Multichannel Flow Analyser 54R10 (figure A.2.2)

Figure A.2.2 Dantec Multichannel Flow Analyser 54R10

A.2.2 Calibration

Anemometers are calibrated using jet wind tunnel and micromanometer.

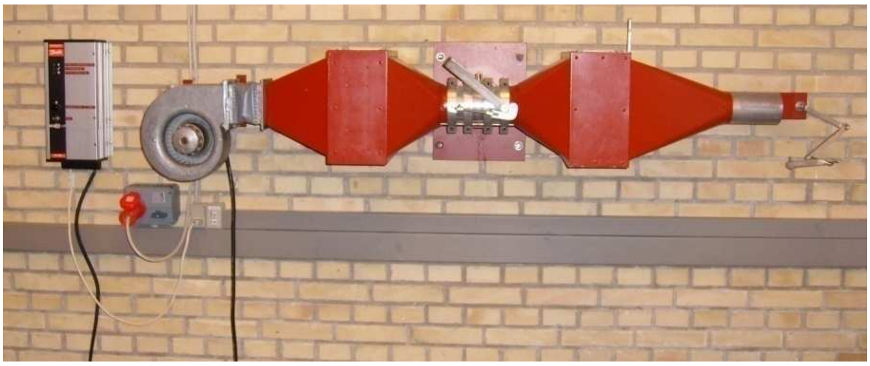


Figure A.2.4. Wind tunel

Figure A.2.3. Micromanometer

An idea is that an anemometer is placed in the center of the circular outlet of the jet wind tunnel. There is also an orifice put in the middle of the tunnel. Velocity measured by anemometer is compared to true one calculated from pressure drop, indicated by micromanometer. In order to calculate velocity there are different equations depending on the diameter of the orifice:

Orifice plate with diameter 10 mm:

$$v = \begin{cases} 0{,}157 \cdot \Delta p^{0{,}485} & if \quad \Delta p > 0{,}5\ mbar \\ 14{,}663 \cdot \Delta p^{0{,}3878} & if \quad \Delta p < 0{,}5\ mbar \end{cases}$$

Orifice plate with diameter 23 mm:

$$v = 0{,}744 \cdot \Delta p^{0{,}4516}$$

Orifice plate with diameter 46 mm:

$$v = 2{,}886 \cdot \Delta p^{0{,}49}$$

Where:

v – velocity $[\frac{m}{s}]$

Δp – pressure difference [mbar]

Since expected values of velocity during measurement are lower than $1\frac{m}{s}$ the range of velocity used in calibration is 0-$1\frac{m}{s}$. Since in displacement ventilation expected direction of the flow is upward and horizontal, calibration for those to directions is made.

An example of calibration curve is given in figure A.2.5

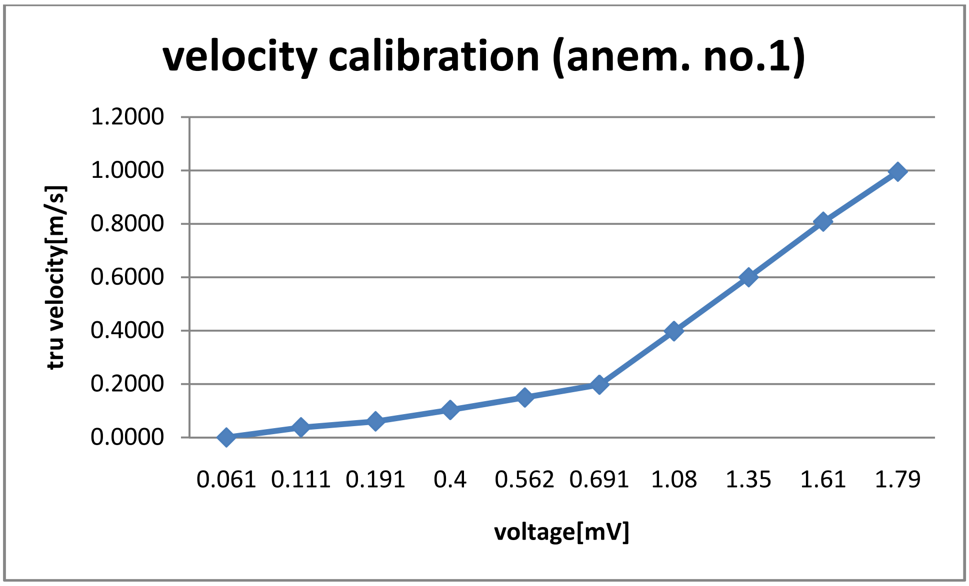


Figure A.2.5 Velocity calibration curve for anemometer no.1

A.3 Tracer gas concentration

In order to measure tracer gas concentration Multigas monitor, Sampler and Doser is used. That device allows to make measurements at 12 different points. Air samples are taken one by one, 40 seconds each. Hence one series of measurement lasts around 7 minutes. Photo of Sampler and Doser is seen in figure A.3.1.

Figure A.3.1 Sampler and doser , INNOVA (tracer gas measuring equipment)

A.4 Smoke equipment

In order to visualize air movement in the room smoke equipment is used. The set includes oil-based smoke machine and remote controller, shown in figure A.4.1

A part of a smoke generator is a bottle filled with oil. The oil is heated and changes a state of matter into gaseous. By means of remote control unit, temperature is controlled in order to obtain a required amount of smoke. Smoke is non-toxic and safe to use.

Figure A.4.1: Oil-based smoke machine with remote controller

In order to find the largest velocity in the exhalation air flow testers" Drager Tubes" are used. It is presented in fugure A.4.2

Figure A.4.2: Air flow tester " Drager Tube"

Summary

Nowadays people spend most of their time inside, whether at home or in a work. Closed environment is the perfect environment for microelements such as viruses or bacteria. Main sources of them are people, who produce them with breathing. Transmision of contaminants from one person to another is called cross infection.

The investigation of this phenomena is the main purpose of the project. Furthermore closer and further surroundings of a person are investigated. For this purpose indoor air parameters such as air velocity, temperature and concentration of contaminants are measured at different points.

Measurements are conducted in a full scale room with dimensions 410x320x270. Displacement ventilation system is provided by means of semicircular diffuser. Two thermal manikins are used to simulate people. Manikins have human body functions such as breathing and heat load releasing. Tracer gas is used to simulate contaminants.

First part of the project are measurements with two manikins. One manikins is source of contaminants and another one is a target. Four different positions of them are investigated. Results show that level of cross infection depends significantly on position and distance between manikins.

Second part are measurements with one manikin. Thermal plume of the manikin and exhalation jet are investigated. Results show that thermal plume is a kind of protection against cross infection.

In third part CFD simulations are presented. Partly they confirm the results from the measurements but they might be only an addition to the measurements.