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Experimental study of the performance of protected zone ventilation used for a reception space

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MASTER THESIS

for

Student Aleksandra Szopa

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Experimental study of the performance of protected zone ventilation used for a reception space

Background

The goal of the project work is to examine the performance of the protected zone ventilation used for a reception in different conditions, e.g. supply airflow rate and supply air velocity, ratio of the supply airflow to the exhaust airflow. Protected zone ventilation was developed to separate the internal space by using plane jet, namely air curtain, to protect occupants from exposure to indoor pollutants. Earlier studies show there is strong and sufficient evidence to demonstrate the association between ventilation, air movements in buildings and the transmission/spread of infectious diseases such as measles, tuberculosis, chickenpox, influenza, smallpox and SARS. In the last two decades, attempts in ventilation field have been made to balance the controversial relationship between airflow distribution and indoor air quality. This project work is connected to a PhD project, 'An efficient airflow distribution method enabling better indoor environment in highly energy performing buildings' and the IEA-EBC Annex 'Design and Operational Strategies for Low Energy and High IEQ Buildings'.

Objectives:

- **Examine** the effect of supply airflow rate and supply air velocity on the performance of the protected zone ventilation
- **Specify** the optimal ratio of the supply airflow to the exhaust airflow
- **Develop** an effective design procedure for receptions using protected zone ventilation

The following tasks are to be considered:

1. Analysis of the current situation of ventilation solutions for receptions and possibilities for the improvement of the performance of current ventilation methods reducing infection risk.
2. Quantification of the influence of supply airflow rate and air velocity on the performance of the protected zone ventilation.
3. Experimental measurement of the airflow distribution of the downward plane jet.
4. Visualization of the performance of the protected zone ventilation.
5. Discussion of results and comparison with previous results.

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Within 14 days of receiving the written text on the master thesis, the candidate shall submit a research plan for his project to the department.

When the thesis is evaluated, emphasis is put on processing of the results, and that they are presented in tabular and/or graphic form in a clear manner, and that they are analyzed carefully.

The thesis should be formulated as a research report with summary both in English and Norwegian, conclusion, literature references, table of contents etc. During the preparation of the text, the candidate should make an effort to produce a well-structured and easily readable report. In order to ease the evaluation of the thesis, it is important that the cross-references are correct. In the making of the report, strong emphasis should be placed on both a thorough discussion of the results and an orderly presentation.

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Pursuant to "Regulations concerning the supplementary provisions to the technology study program/Master of Science" at NTNU §20, the Department reserves the permission to utilize all the results and data for teaching and research purposes as well as in future publications.

The final report is to be submitted digitally in DAIM. An executive summary of the thesis including title, student's name, supervisor's name, year, department name, and NTNU's logo and name, shall be submitted to the department as a separate pdf file. Based on an agreement with the supervisor, the final report and other material and documents may be given to the supervisor in digital format.

☒ Work to be done in lab (Water power lab, Fluids engineering lab, Thermal engineering lab)
☐ Field work

Department of Energy and Process Engineering, 4. Febrary 2015

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Abstract

The objective of this study was to examine the possibilities for the downward plane jet to separate two zones with different pollution concentration. This project work is based on technique called protected zone ventilation (PZV) which using plane jet, namely air curtain. The aim of the downward jet is to prevent transmission of indoor pollutions from target zone to protected zone and reduce exposure of occupant to infection risk. The measurements were carried out to test the performance of the protected zone ventilation for reception space under difference configuration of supply and exhaust airflow rate and supply and exhaust air velocity. In this study used the tracer gas, namely CO_2 to simulate the reside of occupant and their breathing functions during which spreads the bacteria and virus of infectious diseases. During the measurement of CO_2 concentration found that the plane jet is able to divide internal open space to subzones even when the internal velocity will be decrease to about 2.47 m/s (= 78m^3/h) and the volume of exhaust air will be equal to 310 m^3/h. However, the smoke test of supply air distribution shows that the downward plane jet with pollutants will be removed by exhaust system without mixing with ambient air if the exhaust airflow rate was increased to 1065 m^3/h. The results shows that this performance of PZV may be used to reduce the exposure of an occupant to exhaled air from other occupants, nevertheless this kind of study should be still continue to get a better understanding of the performance of the PZV in dependence of conditions and place of applications. This report may be use to comparisons with future study or be starting point to design an efficient PZV system.

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1. Introduction

The well-known and common example of applications of air curtains is the installation in doorways. An air curtains can often be found in doorways of warehouses, hotels and office buildings. The air curtains were used to separate the warm zone from the cold zone. As seem, to protection against the loss of cooling (energy). However, flowing outside air to the cold store causes the freezing of a stored packaging. Therefore, the major aim of air curtains are protect the cold store against the ingress of humid (Kampmann-Maciej Danielak, 2013). Typical applications for air curtains are also machine works hops, large industrial doorways intended for vehicle traffic or other industrial premises. In each of these cases, task of an air curtain forms a barrier for the air flow and isolates the internal space from the external environment. Usually the applications of air curtain is due to the various temperatures of zone. The heat or cold mass (depending on the season) of air try to penetration the internal space buildings. Thus, the jet reduces the free air movement through the doorway and decreasing the transportation of heat and mass through the opening (Sire´n, 2003). Air curtains not only reduces infiltration process, but also protects against the ingress moisture, insects, dust, odours, and contaminations (A.M. Foster, 2007). The next example of applications air curtains internal open public space with different conditions such as restaurant. In this kind of place, the maintenance of high quality air and thermal comfort has a major importance. The temperature of air-conditioned rooms should be kept at the appropriate level. Threat to such objects may be flowing warm air mass for example from kitchen of a restaurant (see 1).

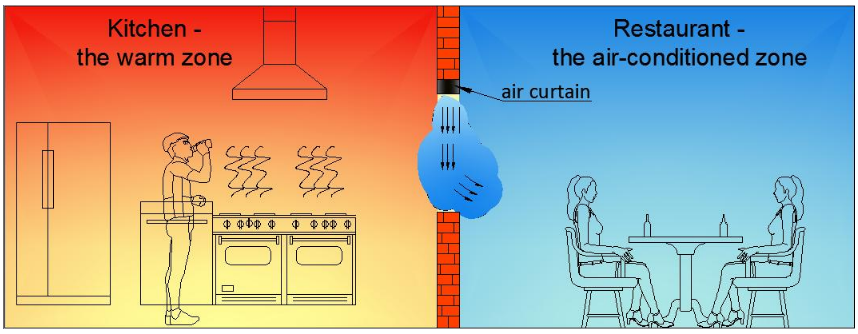

Figure 1. The air curtain used to protect the cool, air-conditioned rooms before the influx of warm air masses

Another reason for the use of air curtains may be increasing distinctions around the world with regard to nicotine limits. In crowded bar or restaurant where a concentration of cigarette smoke is at high level, the workers or other customers are exposure to these harmful substances. Therefore, in order to separate smoking zone from non-smoking zone installed air curtains. Skistad and Bronsema (2004) shows the cases of study which include the performance of ventilation system by using an air curtain. One of them presents the applications of air curtain behind the serving counters, as can be seen in Figure 2.

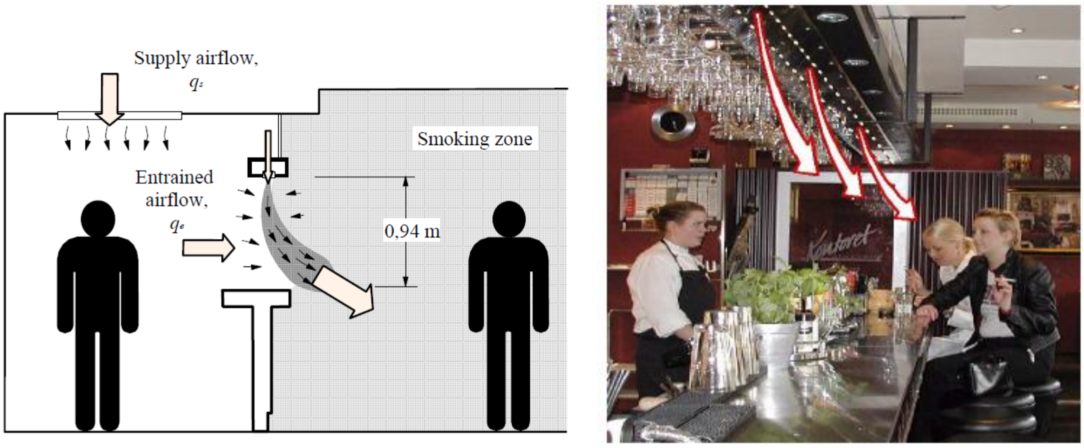

Figure 2. The ventilation air behind the bar is entrained in the air curtain [3]

Other objective of study Skistad and Bronsema (2004) was also to use an air curtain in bar desk (Figure 3).

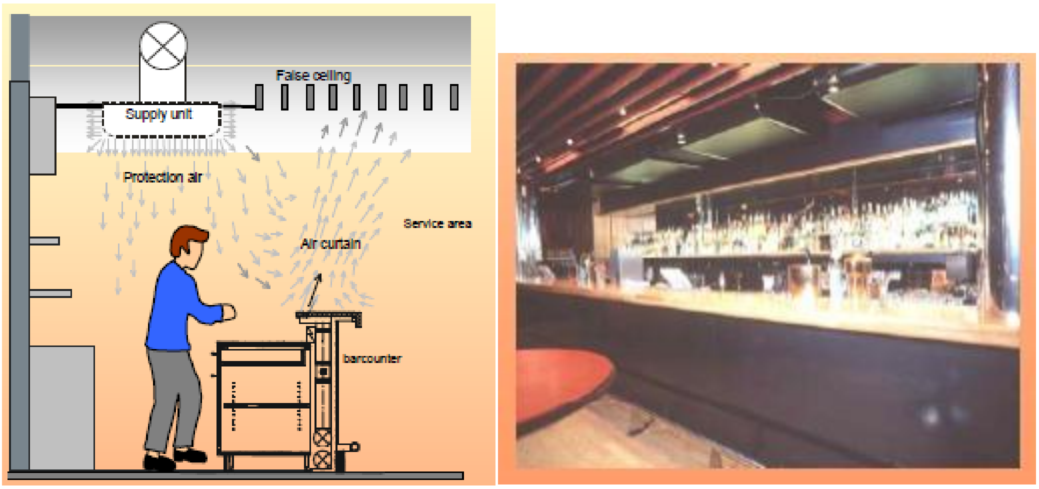

Figure 3. Bar desk with air curtain from [3]

In Guidebook no. 4 is also present design procedure for bar and restaurant space with smoking and non-smoking zone (see Figure 4).

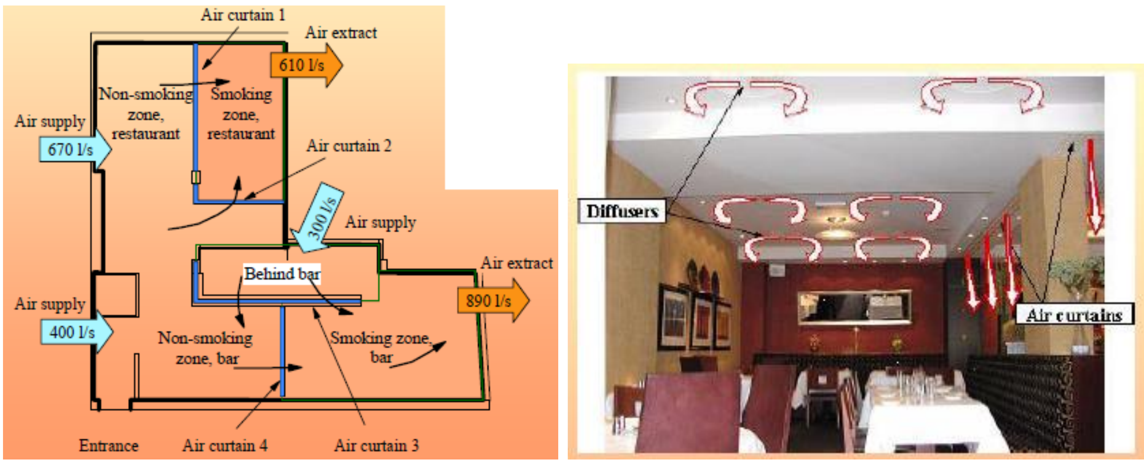

Figure 4. Procedure for bar and restaurant space with smoking and non-smoking zone. Location of zones and air curtains in the restaurant [3]

In this studies shown that air curtains improve the ventilation effectiveness in the smoking zone. The tests shown a contaminant removal effectiveness > 1,5 (Skistad and Bronsema).

An additional issue which became the objective of many studies is widely spreading epidemic respiratory diseases. American soldiers treated in field hospitals during the war in Iraq returned with highly resistant infections such as Acinetobacter baumanii, a microbe that is now epidemic in hospitals worldwide. In 2003, the epidemic of severe adult respiratory syndrome (SARS) focused global attention on the need for infection control. Currently, the problem of multidrug-resistant organisms (MDROs)—"superbugs" such as methicillin-resistant Staphylococcus aureus (MRSA) and extensively drug-resistant tuberculosis (XDR-TB)—is the subject of attention, as transmission becomes a wider problem both in the healthcare system and in the community. MDROs are increasing in prevalence. Statics shows that Healthcare-Associated Infections (HAIs) are among the most common adverse events in hospitals, and the morbidity and mortality associated with them are significant [17]. The Centers for Disease Control and Prevention (CDC) estimate that 1 out of every 25 hospitalized patients develop a healthcare-associated infection each year. In 2011, over 700,000 HAIs occurred in U.S. hospitals, with 75,000 patients dying from complications of HAIs [9]. One of the method improving air quality is providing an adequate quantity of fresh air to an occupied space in order to dilution of indoor pollutant concentrations (Donghyun Rim, 2010). However, Kierat W. (2010) found that mixing ventilation (guidelines air change rate of 12 h^{-1} in hospital) is not able to reduce the risk of airborne cross-infection for a distance close to a coughing sick person.

HOSPITAL HEALTHCARE-ASSOCIATED INFECTIONS, 2011

Type of Infection	Cases
Urinary tract infections	93,300
Bloodstream infections	71,900
Pneumonia	157,500
Gastrointestinal illness	123,100
Surgical site infection	157,500
Other infection sites	118,500
Total	721,800

Source: CDC, 2014a.

Figure 5. Statistics of Healthcare-Associated Infections in 2011 [17]

Therefore, one of solution to reduce HAIs in hospital and health-care facilities could be performance of the protected zone ventilation. Protected zone ventilation was developed to separate the internal space by using plane jet, namely air curtain, to protect occupants from exposure to indoor pollutants and could be key to elimination transmission respiratory diseases . Very similar technique to PZV is protected occupied zone ventilation (POV), was developed to protect office workers from epidemic respiratory diseases. Using POV, an internal space may be divided into different personal work areas or subzones using downward plane jets or air curtains, which separate the space and provide fresh air to the subzones. The plane jets may possibly prevent the transmission of indoor pollution from one zone to other zones and destroy the high concentration exhalation flow directed into the breathing zone of susceptible persons (G. Cao, 2015). Already earlier studies, as Cao (2013), shows that a downward plane jet may be used to control the transmission of airborne contaminants and is able lower significantly personal exposure to the other person's exhaled airflow even when two persons are standing close to each other.

In this project work, the main goal is to examine the performance of downward plane jet in reduction of personal exposure to indoor pollution. The spread of pollutions could be caused by indoor airflows or the human respiratory activities. During a conversation the sick person coughing, sneezing. At this time, the aerosols and droplets with bacteria and viruses may be produced and forwarded to other persons. In fact, the risk of transmission of infectious diseases increases.

The objective of this study will be reception space in hospital or in health facilities with two zones. The aim of this study is to protect one of the zones form exposure to aerosols with bacteria and viruses coming from the target, contamination zone. The particular issue is an opening, which connect both of the zones. The opening conduce to movement of air masses between this spaces and mixing air. In this area, it is very high probability of entering of bacteria from the contaminated zone to the protected zone.

The reception for patient registration may be an example of cross infection due to transmission of infectious diseases. The exposure risk increases when sick persons are talking, sneezing, coughing or even breathing, during which infectious pollutions may be generated. Meanwhile, surrounding people may be exposed to the infectious pollutions. Figure 6. The schema of the transmission bacteria in a exhaled airshows the possible transmission of infectious bacteria and viruses from sick persons to healthy persons.

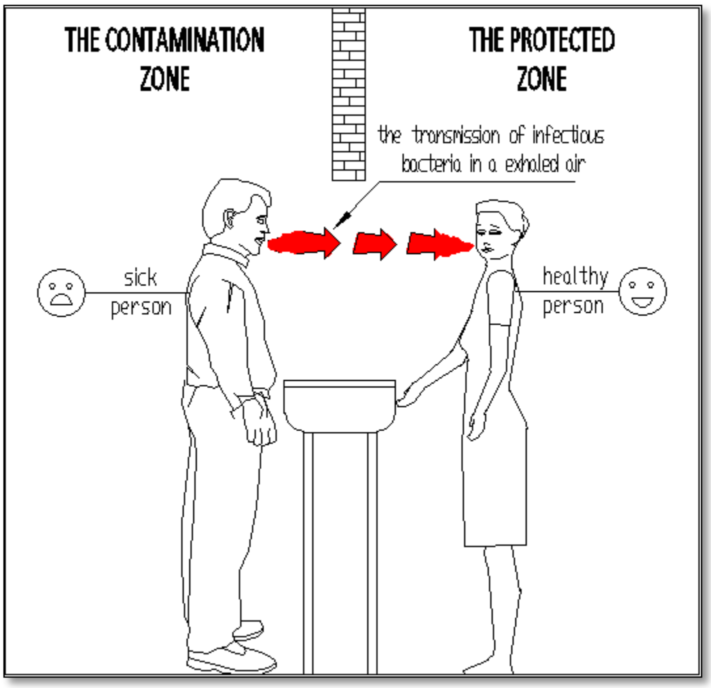

Figure 6. The schema of the transmission bacteria in a exhaled air

2. Theory

2.1. Plane turbulent jet

A slot diffuser may generate an air curtain or a plane turbulent jet. Plane jet characteristic rectangular slot with large width in relation to height. As a result of turbulent motion is also generate the movement of air molecules in a direction transverse to the direction of flow. Extreme molecules beyond a substantial mass of air transferred to the boundary layer and the relatively stationary ambient air a movement that causes the particles to start the air movement in the air flow direction. Therefore, the air volume flow in the jet increases with the distance from the outlet opening , and the air decreases. Figure 7 shows the model of jet from a virtual line source.

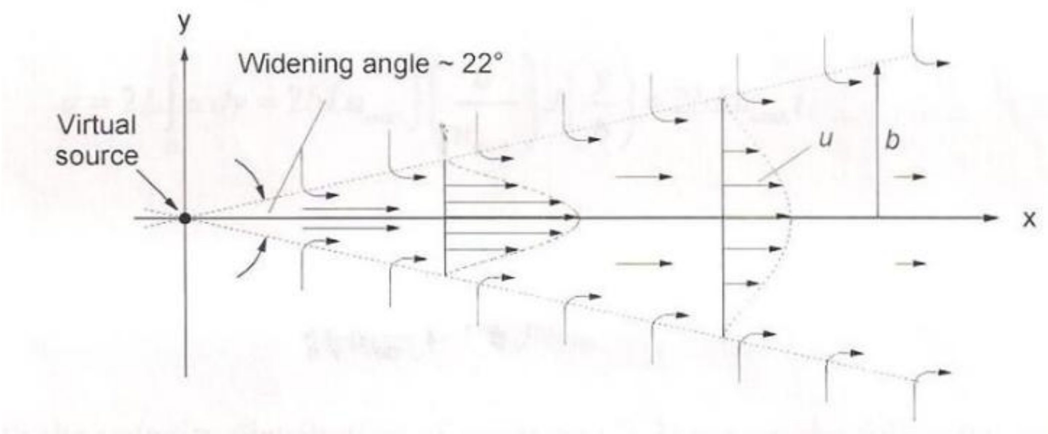

Figure 7. Model of a plane turbulent jet

According to governing law of a turbulence jet this model assumes that the monument flux is constants along the length of the jet. Moreover a turbulent jet spreads with an angle of app. 22°. In a plane turbulent jet defined the following region:

Initial region – jet induces ambient air and therefore increases in volume, the velocity of jet decreases and on the edge of jet reaches zero.

Interaction region – turbulent mixing of the air covers the entire cross-section of stream, i.e. the axial velocity decreases.

Self-similar region – in this region is a characteristic velocity distribution in cross-section, which can be approximated by a Gaussian velocity distribution- the highest velocity is in the axis of the jet and decreases to decay of the centerline velocity.

Terminal region – characterized by a high decrease of centerline velocity. The end of this region occurs when the velocity of jet is equal to the velocity of air in the room.

Figure 8 shows velocity distribution across the jet. The velocity distribution has a bell-shape. In following analyses used the profile suggested by Skåret.

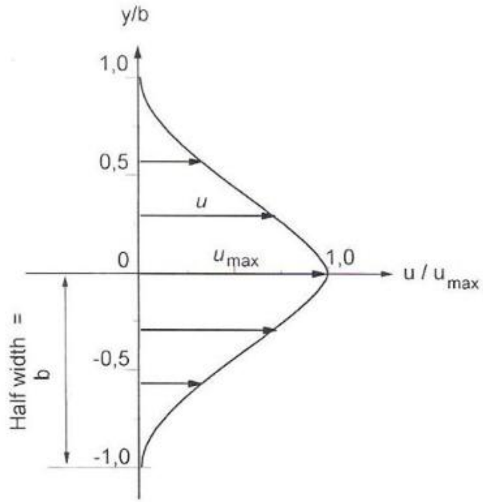

Figure 8. Model of velocity distribution cross the jet

2.2. Theoretical calculation

The first step of the measurement was devoted to outlining a research area, therefore this experimental study started from the theoretical calculation. Below, shows the formulas which are used and the necessary calculations. In the theoretical calculation assumed that the angle of jet will be equal to 22° and then were prepared for four options:

- the maximum velocity of jet in the end area of axisymmetric decay is equal to 1,50 m/s
- the maximum velocity of jet in the end area of axisymmetric decay is equal to 1,00 m/s
- the maximum velocity of jet in the end area of axisymmetric decay is equal to 0,50 m/s
- the maximum velocity of jet in the end area of axisymmetric decay is equal to 0,25 m/s

Moreover, with these calculations could be estimated the amount of exhaust air, taking into account air induction.

- **calculation of width of a turbulent jet**

$$\boldsymbol{b = \tan(\alpha) \cdot x}$$

$where:$

$\alpha - \quad halv\ angle\ of\ a\ jet\ from\ air\ curtain, °$

$x - the\ end\ of\ axisymmetric\ decay, m$

$$b = \tan(11°) \cdot 0{,}9$$

$$b = 0{,}175\ m$$

- **calculation of height coordinate**

$$\boldsymbol{z = 2 \cdot b}$$

where:

$z - height\ coordinate$

$$z = 2 \cdot 0{,}175$$

$$\boldsymbol{z = 0{,}35\ m}$$

- **calculation of volume of exhaust air**

$$\boldsymbol{q_{0,9} = x \cdot z \cdot u_{max}}$$

where:

$q_0 -\ volume\ of\ air\ on\ lenght = 0{,}9\ m,\ m^3/h$

u_{max} – maximum $velocity\ in\ \ the\ end\ of\ axisymmetric\ decay$

$$q_{0,9} = 0{,}9 \cdot 0{,}35 \cdot 1{,}5$$

CASE I (u_{max} = 1,5 m/s): $q_{0,9} = 0{,}473\ m^3/s = 1703\ m^3/h$

CASE II (u_{max} = 1,0 m/s): $q_{0,9} = 0{,}315\ m^3/s = 1134 m^3/h$

CASE III (u_{max} = 0,5 m/s): $q_{0,9} = 0{,}158\ \ m^3/s = 567\ m^3/h$

CASE III (u_{max} = 0,25 m/s): $q_{0,9} = 0{,}079\ m^3/s = 284\ m^3/h$

- **calculation of monument flux**

$$\boldsymbol{J = x \cdot z \cdot u_{max}{}^2 \cdot L \cdot I \cdot q}$$

where:

$J - impulse, momentum\ , kgm/s^2$

$q -\ air\ density, m^3/h$

$L - lenght\ of\ air\ curtain, m$

$I - index$

$$J = 0{,}9 \cdot 0{,}35 \cdot 1{,}5^2 \cdot 1 \cdot 0{,}452 \cdot 1{,}2$$

CASE I (u_{max} = 1,5 m/s): $J = 0{,}384\ kgm/s^2$

CASE II (u_{max} = 1,0 m/s): $J = 0{,}171\ kgm/s^2$

CASE III (u_{max} = 0,5 m/s): $J = 0{,}043\ kgm/s^2$

CASE III (u_{max} = 0,25 m/s): $J = 0{,}011\ kgm/s^2$

- **calculation of internal velocity of jet**

$$\boldsymbol{u_0} = \sqrt{\frac{\boldsymbol{j}}{\boldsymbol{q \cdot d}}}$$

where:

$u_0 -$ $initial\ velocity\ of\ jet, m/s$

$d -$ $diameter\ of\ slot, m$

$\boldsymbol{d = 0,009\ mm}$

$$u_0 = \sqrt{\frac{0{,}384}{1{,}2 \cdot 0{,}009}}$$

CASE I (u_{max} = 1,5 m/s): $u_0 = 5{,}963\ m/s$

CASE II (u_{max} = 1,0 m/s): $u_0 = 3{,}98\ m/s$

CASE III (u_{max} = 0,5 m/s): $u_0 = 2{,}00\ m/s$

CASE III (u_{max} = 0,25 m/s): $u_0 = 1{,}01 m/s$

- **calculation of volume of supply air**

$$\boldsymbol{q_0 = u_0 \cdot d \cdot L}$$

where:

$q_0 -$ $volume\ of\ supply\ air, m^3/h$

$$q_0 = 5{,}963 \cdot 0{,}009 \cdot 1$$

CASE I (u_{max} = 1,5 m/s): $q_0 = 0{,}054\ m^3/s = 194\ m^3/h$

CASE II (u_{max} = 1,0 m/s): $q_0 = 0{,}036\ m^3/s = 130 m^3/h$

CASE III (u_{max} = 0,5 m/s): $q_0 = 0{,}018\ m^3/s = 65\ m^3/h$

CASE III (u_{max} = 0,25 m/s): $q_0 = 0{,}009\ m^3/s = 33\ m^3/h$

- **calculation of volume of induced air**

$$\boldsymbol{q_e = (q_{0,9} - q_0)}$$

$$q_0 = 0{,}054 \frac{m^3}{s} \qquad q_{0,9} = 0{,}473 \frac{m^3}{s}$$

CASE I (u_{max} = 1,5 m/s): $q_e = 0{,}42\ m^3/s = 1512\ m^3/h$

CASE II (u_{max} = 1,0 m/s): $q_e = 0{,}28\ m^3/s = 1008\ m^3/h$

CASE III (u_{max} = 0,5 m/s): $q_e = 0{,}14\ m^3/s = 504\ m^3/h$

CASE III (u_{max} = 0,25 m/s): $q_e = 0{,}07\ m^3/s = 252\ m^3/h$

- **caltulation of volume of induced air from right or left side**

CASE I (u_{max} = 1,5 m/s): $q_{e_R} = 0{,}21\ m^3/s = 756\ m^3/h$ $\quad q_{e_L} = 0{,}21\ m^3/s = 756\ m^3/h$

CASE II (u_{max} = 1,0 m/s): $q_{e_R} = 0{,}14\ m^3/s = 504\ m^3/h$ $\quad q_{e_L} = 0{,}14\ m^3/s = 504\ m^3/h$

CASE III (u_{max} = 0,5 m/s): $q_{e_R} = 0{,}07\ m^3/s = 252\ m^3/h$ $\quad q_{e_L} = 0{,}07\ m^3/s = 252\ m^3/h$

CASE III (u_{max} = 0,25 m/s): $q_{e_R} = 0{,}035\ m^3/s = 126\ m^3/h$ $\quad q_{e_L} = 0{,}035\ m^3/s = 126\ m^3/h$

It should be recognized that this theoretical calculation were used to outline the order of magnitude the values of air parameters in this study and also to selecting equipment (like supply or exhaust fan) which were necessary to perform the ventilation system in the test room. This values could be oversized because during the calculation the setpoints were not sufficiently accurate e.g. angle of jet. Next, the really measurements will show that the volume of supply or exhaust air should be reduced or increased.

3. Experimental setup

3.1. Experimental chamber

The measurements of this study were performed in the laboratory of the Department of Energy and Process Engineering at the Norwegian University of Science and Technology (NTNU). The test room of the total useful area 20.7 m^2 and a height equal to 2.4 m is divided into two zones with different volume. The test room was divided by an inner wall, which is 10 cm thick. An opening , which has dimensions of (width × length × height) 0.1 x 0.98 x 1.02 m, was made in the internal wall. The location of the opening and all dimensions of the test room can be seen in Figure 9.

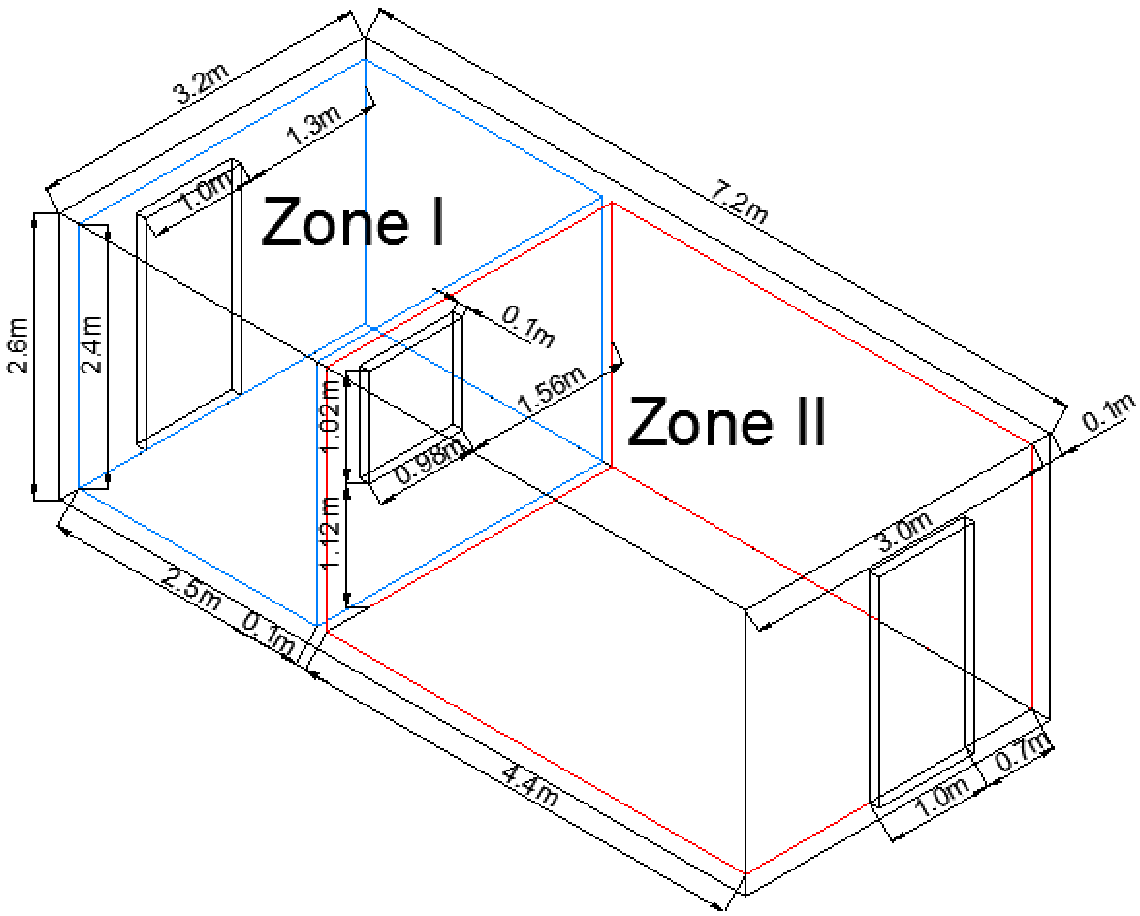

Figure 9. Sketch of measurement set-up

The chamber may represent a reception of a hospital or in health facilities. The first zone is dedicated to the workplace of employees at the reception. In this paper, this space is called 'protected zone', 'clean zone' or identified as no I. The floor area of the zone I is 2.5 x 2.4 meters and the ceiling height is 2.4 meters. The second zone simulates place of patient admissions and waiting room. The geometry of this space is equal to 3.0 x 4.4 x 2.4 m (width x length x height). In this report is called ' contaminated zone', 'polluted zone' or no II. Moreover, both of the zones have separate entrances. The doors are located in the middle of external walls and have dimensions 1.0m x 2.1 m (Figure 9).

3.2. Current situation of ventilation in the test room

As is apparent from the foregoing description (3.1. Experimental chamber) in the test room there is not any mechanical system of ventilation. The process of supplying and removing air is performed naturally, without using mechanical device. The exchange of the air between the building and the external environment takes place by doorways and leakages. The purpose of the current report is to study the possibility of protecting the selected zone by using an air curtain. Due to this fact, the ventilation system with the necessary equipment was designed and implemented to realize the goal of the experiment. This system consists of two layouts:

- the supply air installation;
- the exhaust air installation.

The calculations which have been made in order to design the systems of ventilation are shown in 2.2. Theoretical calculation.

3.3. Supply air system

The supply system of ventilation is performed from circular tubes and fittings with external diameter 160 mm. The components are made of galvanized steel or flexible aluminum type FLEX. Supply system is powered by a supply air fan type CK 160 manufactured by the company Östberg. The CK is duct fan with diameter 160 mm and have casings manufactured from galvanized steel and is moisture resistant. The fan was connected to Thyristor Controller VRS which control the voltage variation regulators. The VRS controller is used to manual variable speed control of single-phase motors. Minimum speed is adjusted by means of a screw under the knob. The fan is located outside of the test room, as shown in Figure 10. Photos of location the supply air fan

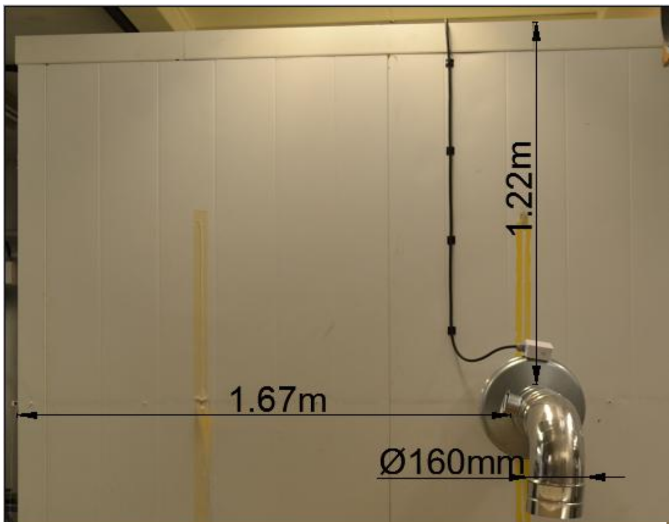

Figure 10. Photos of location the supply air fan

The fresh air is provided form laboratory hall to installation by the suction fan and then is distributed by the air curtain. The air curtain is in the shape of cuboid in dimensions of (width × length × height) 0.2 x 1.0 x 0.2 m and was manufactured from galvanized steel (see Figure 11).

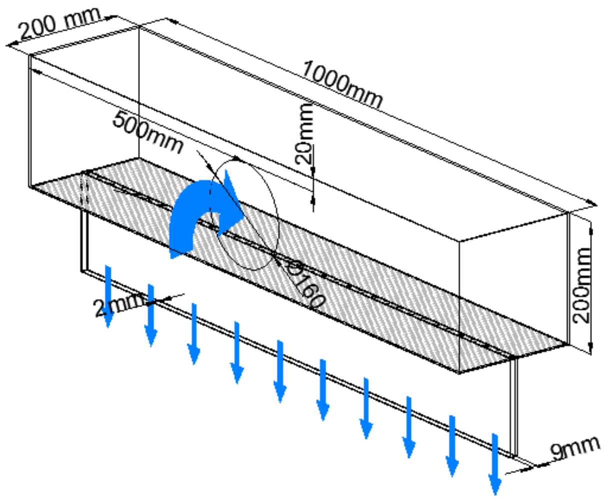

Figure 11. Schematic drawing of the plane jet diffuser

The air curtain was placed in the ‘contaminated zone’ 5 cm below the ceiling. The air curtain will separate the ‘protected zone’ with the ‘contaminated zone’,. Inside the supply opening, there are small nozzles with the internal diameter 9 mm. The distance between these nozzle and the slot is 1.02m. Moreover, to smooth the supply airflow distribution along the slot and to reduce flow turbulence in the air curtain, the perforated plate was mounted inside. The plate with dimensions of 19,06 x 98,06 cm was made by aluminum. This slot, which is used to produce an air curtain, has dimensions of (internal width x length x height) 0.009 x 1.0 x 0.15 m (see Figure 11). For theoretical calculation, the effective outlet area of the slot equals to 0.009 m^2. As already mentioned, the fan speed and related parameters such , the velocity and airflow rate are regulated by Thyristor Controller. However, this parameters can be also changed by using the dampers. In this system, it was installed closing damper with diameter 160 mm and is made from galvanized steel. The damper has been installed before intake fan, outside the test room. All the other dimensions and distances form fixed structures have been shown in Figure 12.

Figure 12. Photos of the supply air system

3.4. Exhaust air system

The exhaust air system is also performed form circular tubes and fittings. The the external diameter of tube is equal to 315 mm. The ducts are manufactured from galvanized steel. The main aim of this system is removing the contaminated air by using the exhaust fan. This fan produced by Östberg company is duct device with diameter 360 mm and have casings manufactured from galvanized steel. The fan is also connected to the Thyristor Controller VRS and the parameters such as fan speed and airflow may be regulated by this device.

Figure 13. Photos of location the exhaust air fan

The outlet opening is located at height 1.12 m, under the air curtain, at the distance 0.89 m. The exhaust vent in a shape of rectangular has an internal dimensions of width, length equal to 0.32 x 1.0 m and following this, the maximum effective area is equal to 0.32 m^2 (Figure 14. Geometry of local exhaust).

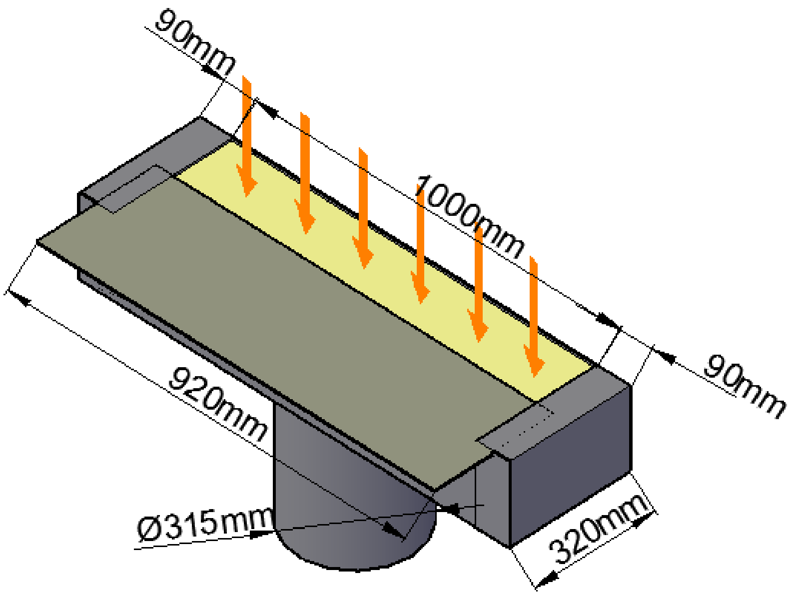

Figure 14. Geometry of local exhaust

This outlet air nozzle has a manually sliding closure thus, the exhaust area can be changed. This performance allows to regulate of exhaust airflow rate form under the air curtain. Moreover, the airflow rate can be also controlled by the damper which is installed in this system. The lens-type damper is installed in the middle of the installation inside the test room, as can be seen in Figure 15.

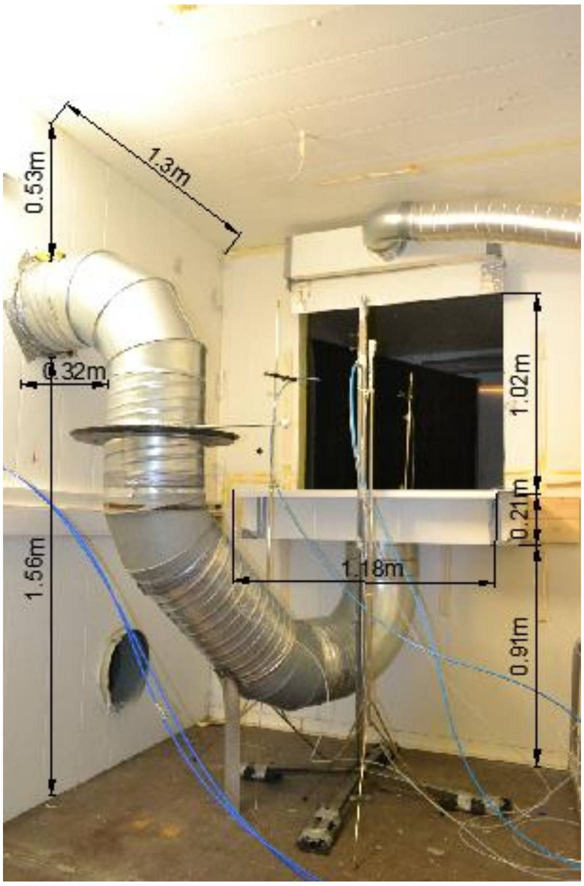

Figure 15. Photos of the exhaust air system

3.5. Method section

This project work concerns to how an air curtain or downward plane jet may reduce the direct exposure of a person to pollutants produced by exhalation. In this study will be analyze the selected parameters of air in relation to the possibilities of using them to separate the affected area and an impact this parameters on the thermal comfort and improving indoor air quality. The effectiveness of the airflow distribution system will be analyzed in terms of that is able to prevent the transmission indoor pollution. This experiment focusing on using the mechanical system of ventilation, precisely by using plane jet, namely air curtain, to protect the selected zone. This kind of ventilation (PZV) can be use to protect occupant zone for e.g. in the hospital in a situation where two people have a contact, one of them is a healthy person and second person is a sick patient. In order to examine the possibilities of a plane jet to protect the selected zone carried out the experimental measurements.

Figure 16 shows the schema of concept the airflow distribution for a reception based on protected zone ventilation. The fresh air will be supplied by the supply air system and then will be distributed by downward plane jet

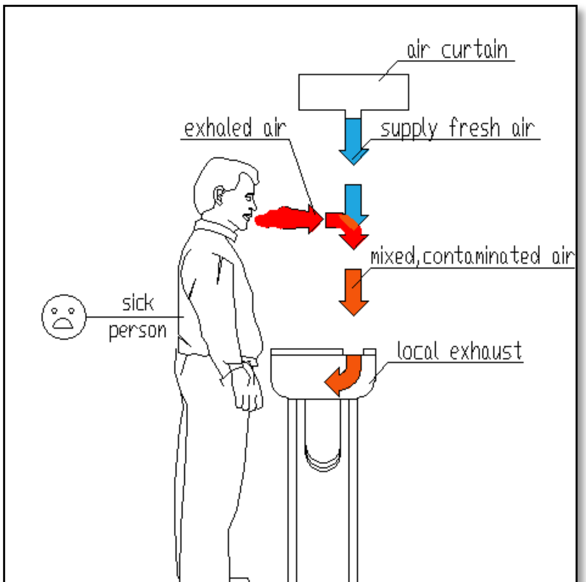

Figure 16. The designed procedure for reception space using the protect ventilation zone

(which will be locate near the source of contamination, along the opening). The supplied air will form a kind of ‘’ air wall’’ or air curtain. The air curtain may prevent the transmission of the indoor pollutants from one zone to another zone. So the indoor space will be divided into two subzones, one is a protected zone and the other is a polluted zone. The air curtain will bring the produced and transmitted pollution down to the exhaust at the table level. The pollutants of the indoor environment may be just generated by a sick person during the breathing process, in which infectious particles may be exhaled. In the end, all downward airflow with pollutants will be removed by the exhaust air system.

In this study, the implementation of the exhaust below the air curtain, in the reception counter has also a major importance. The exhaust should be carry out that the jet flows directly to the outlet opening. This solution should ensure, that pollutants which are transported in a stream of a supply air get not again to the internal environmental, but will be exhaust to the outside of chamber. The goal of the local exhaust ventilation is to prevent the mixing air inside the room. In case, if the exhaust will be not located near sources of pollution, probably the axisymmetric stream generated by the air curtain will be spread evenly over the two sides at the moment of a contact with the horizontal plane. In such a situation the induced, partially contaminated mass of air could be transmit to the protect zone and pose a threat to resident occupant, the problem is illustrated in Figure 17.

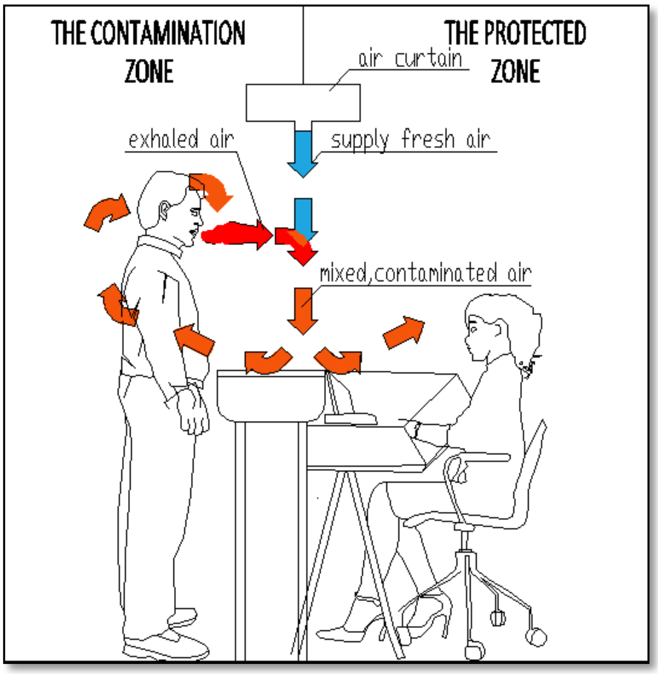

Figure 17. Sketch of using a air curtain without a local exhaust

As is known, this project work is based on using the protect zone ventilation(PZV). However, this study also combines elements of others types of ventilation. One of them is close to the protect zone ventilation, namely protect occupant ventilation (POV). In fact, the measurement area of this study fits in the dimensions dedicated to protect occupant zone (width = 1.5 m, length =1.5 m, height = 1.8 m). Moreover, the zone protection is combined with occupants protection who stay in a person’s working area. Another type of ventilation which is woven into the development, is personal ventilation. The supply and exhaust air devices are located near space of resident people. The fresh air is supplied at standard height head in standing and sitting positions in order to using clean, fresh air to breathing process. Similarly as in the personal ventilation, the outlet is located close occupant zone.

The last element is relevant with piston ventilation. The contaminations in the downward plane jet will be transport vertically from upper part of a room to outlet located below (as shown Figure 18).

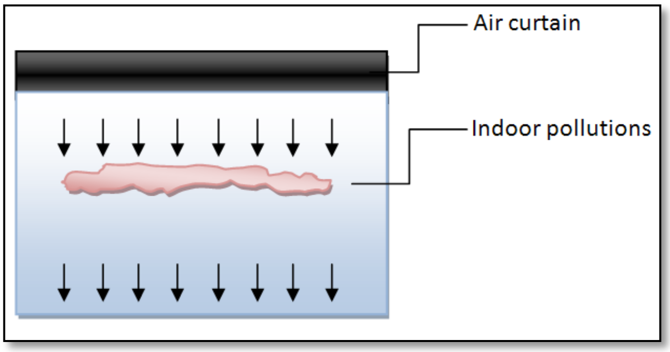

Figure 18. Schema of piston ventilation

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4. Measurement setup

During the measurements a few parameters of airflow were focused on, namely parameters of the airflow which was distributed from the air curtain and the air parameters in the test room. The examined parameters:

- the supply airflow rate, m^3/h
- the exhaust airflow rate, m^3/h
- the velocity of the downward plane jet, m/s
- the concentration of carbon dioxide in the air, ppm

The main hazard associated with these parameters like a draft, which affects thermal comfort and an increase in the concentration and spread of CO_2 resulting in exposure to pollutants protected zone. Therefore, each of parameters assigned the ultimate goal for which

- the value of this parameters are possible to achieve;
- the value of this parameters is the most effective;
- the balance between other parameters of airs is preserved;

The measurements were carried out when it was found that the criteria of the ultimate goal has been fulfilled.

Some of the parameters are closely related , such us the supply airflow rate and the velocity of the downward plane jet. Namely, if the supply airflow rate decreases , the velocity of the downward plane jet also decreases, assuming that the effective area of slot is constants. Another example a close linkages between the air's parameters is the supply airflow rate and the exhaust airflow rate. The volume of supply air would determine the volume of exhaust air to avoid the transmission of pollutant from one zone to another. Therefore, all these parameters like: velocity of the downward plane jet, supply airflow rate and supply airflow rate need to be optimized to reach the goal. The value obtained of this parameters should be the minimal because if the velocity of supply air is smaller than the risk of draft became smaller. Following this, for the CO_2 concentration also was determined the goal of measurement. In this study seek to protect the select zone

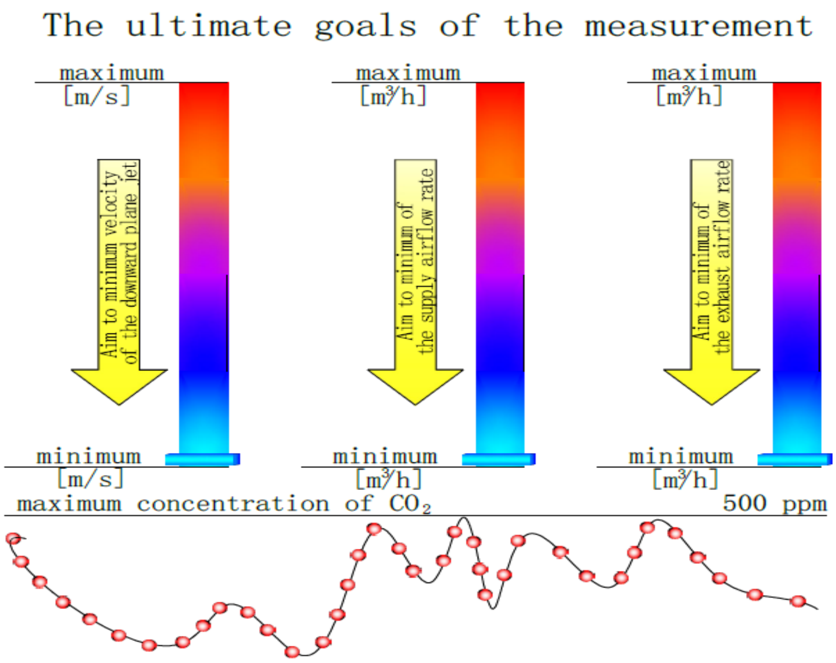


Figure 19. Sketch of the ultimate goals of measurement

against influence of indoor (CO_2). The protection zone is equivalent to the CO_2 concentration at the level of less than 500 ppm.

4.1. The measurement of supply and exhaust airflow rate

As pointed out, the task of this measurement was to find a minimal but sufficient volume of air which allows to protect the selected zone. At the same time, when conducted the measurements of airflow rate, the CO_2 concentration was also recorded. This measurements should be taken to ensure that the volume of supply or exhaust air are sufficient to block the transmission of indoor pollution and to protect the zone. To find appropriate solution had to regulate the amount of air. To regulate this parameters used the VRS controller, namely regulation by using the knob of VRS controller and dumpers. The type and localization of this device was described in Chapter Experimental setup. Together with a change of position of the knob changes the rate of supply or exhaust air. Due to fact that the knob of VRS controller had a graphic scale so the first step of measurement of supply and exhaust airflow rate was to assigned the position of knob to the value of airflow rate.

The single-plane dumper at supply air system was always equal 60°. Therefore, the volume of supply air was only regulated by VRS controller. To identify the volume of supply air depending on the position of knob carried out the measurement of the internal velocity of jet. To this measurement used a special device called VELOCICALC Plus Model 8388. The VELOCICALC PLUS measures air velocity, temperature, differential pressure, and calculates volumetric flow rates. In addition Model 8388 measures relative humidity and calculates dew point from the temperature and relative humidity readings. The Model 8388 has a telescoping prob. The VELOCICALC PLUS can store individual readings and compute the average of these readings[13]. The TSI VELOCICALC Plus Model 8388 is shown in Figure 20.

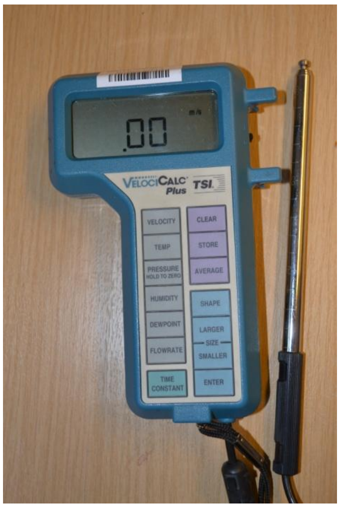


Figure 20. VELOCICALC Plus Model 8388 [13]

The measurements of the internal velocity were done at 11 different points, in increments of 10 cm along the slot of air curtain. The results considered as valid because each values of velocity at the slot air curtain did not differ then 20% of the average of this velocity. Additionally, assumed that the average velocity is equal the internal velocity of jet (u_0). Thereafter used the following formula to calculate the real rate of supply air from air curtain.

$$q_{sup} = u_0 \cdot A_{eff} \; [m^3/h]$$

Specify:

$q_{sup} - supply\ airflow\ rate\ [m^3/h]$

$u_0 - \ internal\ velocity\ of\ jet\ [m/s]$

A_{eff} $-$ $effective\ area\ of\ slot\ jet$

To verify the correctness of the performed measurements and calculations, the supply airflow rate measured also by using balometer type TSI Model 8371 AccuBalance . The AccuBalance capture hood is an instrument designed to measure the air flow from diffusers and grilles or the air flow entering exhaust outlets. The instrument can display the measured air flow in four different units: standard cubic feet per minute (SCFM), standard liters per second (Std l/s), standard cubic meters per hour (Std m^3/hr),and standard cubic meters per minute (Std m^3/min). All readings may also be displayed in actual flow conditions. The AccuBalance capture hood consists of a fabric hood, a molded plastic base which contains an electronic meter, and a flow sensing manifold located within the base [10]. Air flowing through the hood is measured by a hot-film sensor located in the central hub of the flow sensing manifold. The AccuBalance® capture hood has a built-in electronic flow meter. The twenty-four pairs of flow sensing ports in the manifold are strategically located so that the AccuBalance® capture hood provides the highest degree of measurement accuracy, even in no nuniform flow conditions.

The balometer was placed under the air curtain, next to the outlet of the slot. The compare of this results was are summarized in Table 5. The summary results of measurements of the supply airflow rateChapter Measurement results of CO2 concentration.

In case of the measurement of the exhaust airflow air used both of devices to regulate this parameter, namely the damper and VRS controller. In addition, the rate of exhaust was changed by manually sliding closure located in the reception counter. After set up this three control device carried out measurement of the volume of exhaust air. To examine the airflow rate from the exhaust air system used also balometer. This device was placed at a horizontal position, near to the exhaust fan as to the entire volume of exhaust air flowed through the inside of the balometer. The outputs was displayed in standard cubic meters per hour (Std m^3/hr). The time of measurement took about 2 minutes and then the results was averaged.

4.2. The measurement of CO_2 concentration

One of the issue of this experimental study is a transmission/spread of indoor pollutants, such as infectious diseases and exposure occupants to this pollutants. To simulate this contamination used the tracer gas, namely carbon dioxide. Thus, the appropriate amount of carbon dioxide equal to CO_2 concentration in the exhaled air was possible to imitate the resisting people in the test chamber who spread the infectious bacteria and viruses during respiratory activities. To define the amount of dosed CO_2 was set out:

- the number of simulated people who residents in the test room,
- the physical activates of the occupants.

According to ISO Standard 16000-26:2012, the specific emission rate CO_2 ($q_{V,CO2}$) is equal to 30l/h for one occupant who characterized the light work. In this study was assumed the residence of two people, thus the total rate of dosed CO_2 was equal to 60l/h. The layout of dosing CO_2 had its beginning on the cylinder with the tracer gas. The gas cylinder was located outside the test room (Figure 21). This bottle was equipped with devices to control the pressure inside the cylinder, called manometers and two control valves to regulate of CO_2 rate. The gas bottle was connected with the distributing wire made of polyethylene with diameter 6x4mm. The distributing wire fed the rotameter which controlled the flowrate of carbon dioxide. This flowmeter was operated manually to the float showed the required amount of carbon dioxide. Subsequently, the main wire was separated into two wires of the same length. The ends of wires were located at height 1.6 m which represent the breathing zone of a standing person. The bats with dosing CO2 wire were spacer at distance 0.3m. Moreover, the distance between the ends wire and the axis of downward jet in a straight line is equal to 0.43m.

Figure 21. The localization of the cylinder with a tracer gas

In other side of jet, namely in the protect zone were located two sampling points (no. 1 and no. 2) to analyze the CO_2 contamination. The measurement of concentration was taken at two heights, 1.1 (no. 2) and 1.6 m (no. 1), which represent the breathing zone of a sitting person and a standing person. This sampling points targeted to report about the actual exposure of occupants to indoor pollutions.

Other four sampling points were located in the polluted zone(no. 1). Two of them (no. 3 and no. 4) were used to control of CO_2 concentration in the supply and exhaust air therefore, one probes was pointed in a supply tube (no. 3), second was in an exhaust tube (no. 4). The probe (no. 3) was responsible to alerting when the CO_2 concentration in a supply air would be higher than the CO_2 concentration inside the test room. The high CO2 concentration in a supply air could become a cause of increased CO_2 concentration inside of the room and disrupt the measurements. Moreover, the probe (no. 4) was used to verify the efficiency of removal the indoor pollutions by the ventilation system.

The last two probes (no. 5 and no. 6) were used to monitor the CO_2 concentration in the polluted zone. The probe no. 5 was placed close to one of the ends of dosing CO_2 wire. The function of this probe was measured the CO_2 immediately at the point of dose carbon dioxide and the control the correct operation the CO2 dosing system whether the CO_2 concentration maintained at the same level . In case decrease of CO_2 concentration could indicate such as an insufficient amount of tracer gas. The probes no. 5 was at height 1.6m. The probe no. 6 was placed behind the probes no. 5 at a distance about 0.45m and at height 1.6m. This sampling point was representative of CO_2 concentration in the polluted zone. The result received from probe no. 6 informed about the exposure to the negative impact pollution such as viruses, bacteria of other patients w.

As mentioned above, all the sampling points formed the analyze system of CO_2 concentration and were connected to Bruel & Kjćr 1302 Photoacoustic Gas-Monitor and a Bruel & Kjćr Multipoint Sampler and Doser Type 1303.

Figure 22. The Multipoint Sampler and Doser Type 1303

This device is used to measurement air quality in many different conditions, in different environments. Therefore, the gas-monitoring equipment is flexibility and provide sensitive and accurate monitoring. The Multipoint Sampler and Doser Type 1303 is remote-controlled from a personal computer to provide a monitoring system which fulfils the above requirements of flexibility, sensitivity and accuracy. The 1303 greatly increases the area monitoring capabilities by drawing air-samples through tubing from up to 6 different sampling points – each being up to 50m distant – and delivering the samples to the 1302. Moreover the Multipoint Sampler and Doser has ability to dose of tracer gas in or measurement of temperature by using 6 temperature transducers, connected to the 1303 which can be positioned at the sampling/dosing points to give fuller information about the environment at that point. However, this capabilities of the 1302 were not used in this experimental study. The pneumatic system of the 1303 is shown schematically in Fig.6.

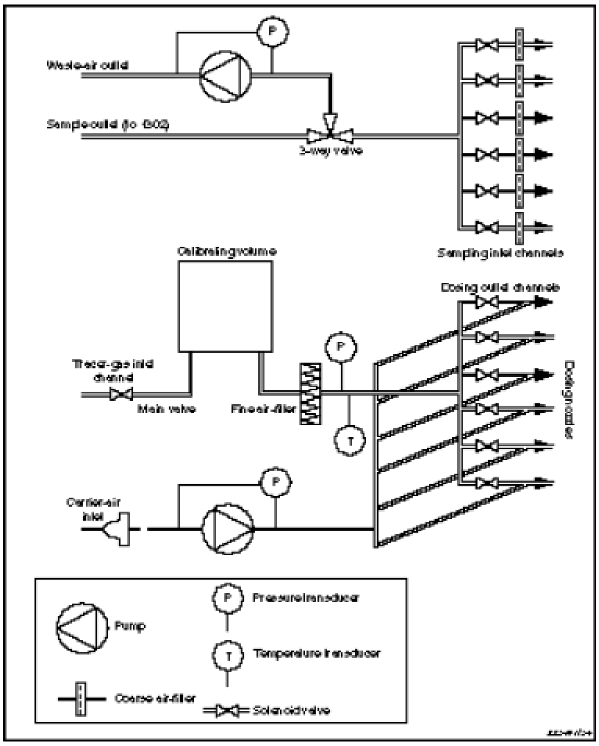


Figure 23. A schematic diagram of the 1303's pneumatic system: the sampler system is depicted at the top, the dosing system at the bottom.

The use of non-reactive materials throughout minimizes gas adsorption in the internal air-channels [11]

The sampler system has 6 inlet channels, each with a solenoid valve. Each inlet channel has a tube-mounting stub on the front-plate of the 1303. The 6 inlet channels converge into one; a three-way valve can then direct the gas sample to the 1302 for analysis, or through the pump to the waste-air outlet on the 1303's back-plate. A pressure transducer checks the efficiency of the sampling pump and allows checks for blocked airways. Using the 1303's sampler system does not slow the 1302's monitoring capability: transporting a gas-sample from a sampling point 50m distant takes approximately 25s – less time than the 1302 takes to complete a measurement cycle. An air-filter is attached to the end of each sampling tube to keep the samples free of particles [11].

All results of measurements were send to PC computer and next by using Application Software Type 7620 User Manual (see Figure 24) were presented on the graph or in the table summarizing. The measurement for one case took about one and a half hours. For each case was a different setpoints, namely various airflow rate of supply and exhaust air.

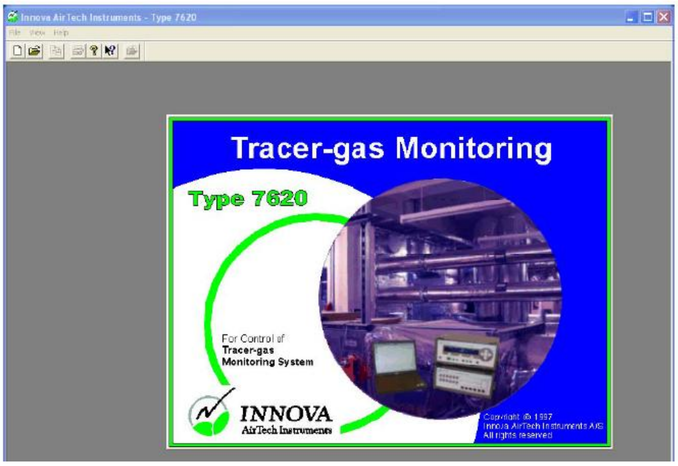


Figure 24. Application Software Type 7620 User Manual

4.3. The measurement of velocity of the downward plane jet

One of the tasks of this study is to carry out experimental measurements of the airflow distribution of the downward plane jet. The measurements may contribute to characterize the dimensions of a jet and also could be useful to analyze the internal zones which are exposure to draught of sitting people near the supply of a jet. This examination was carry out in three cases:

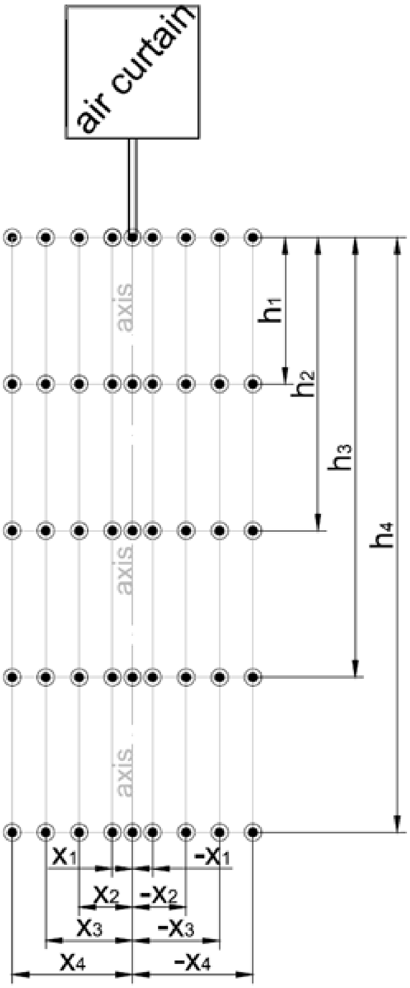
- for a supply and exhaust airflow rate which were the most effective and allowed to protect the select zone during the measurement of CO_2 concentration;
- for a supply and exhaust airflow rate for which the flow air was the most appropriate, namely during the visualization of smoke gas the supply air flow was transported vertically downwards, absorbing the indoor pollution and then the entire quantity of air was discharged to exhaust outlet without spreading of the smoke gas into test room;
- for only a supply airflow rate to check the distribution of jet without the exhaust air system.

In this measurement five air velocity transducers were used (TSI 8475) (Figure 25. The 8475 Air Velocity Transducers). The 8475 Air Velocity Transducers are ideal for both temporary and permanent installations for air velocity measurements in research and development labs, manufacturing processes, and other applications. The full–scale range, signal output, and time constant are user selectable and can be easily changed to meet the needs of your application.

Figure 25. The 8475 Air Velocity Transducers

Before the really measurement, the anemometers were calibrated. During the measurements, the anemometers were placed on the stick one above the other at the distance 0.22cm. The highest anemometer was positioned on the level of the air curtain's slot whereas, the lowest anemometer was located on the level of outlet air nozzle. The measurements of velocity could be divided into three parts:

- the measurements in the polluted zone along the axis of the slot jet at the distance x_1=3cm, x_2= 8cm, x_3=12cm, and x_4=18cm and on five different heights h_0, h_1, h_2, h_3, h_4,
- the measurements along the axis of the slot on five different heights,
- the measurements in the protect zone along the axis of the slot jet at the distance -x_1= 3cm, -x_2=8cm, -x_3=12cm, and –x_4=18cm and on five different h_0, h_1, h_2, h_3, h_4.



No.	Sign	Distance
1.	h_0	The level ''zero'' on the height of slot jet
2.	h_1	22 cm
3.	h_2	44cm
4	h_3	66 cm
5.	h_4	88 cm

Figure 26. The measuring points of the velocity of the downward plane jet

In order to obtain accurate results taking into account the uneven flow along the slot of air curtain, the measurements were performed in three planes, as shown in Figure 27.

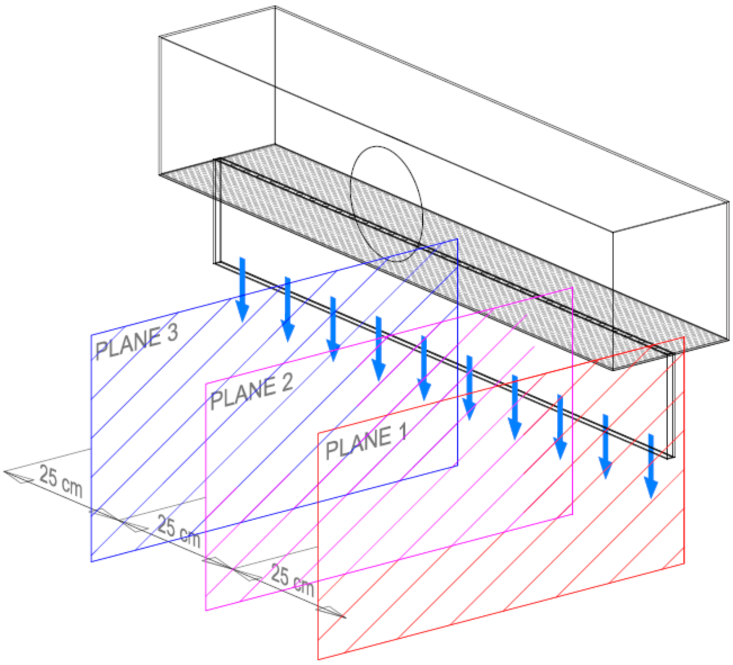


Figure 27. The schema of measurement velocity

The measurement results from air velocity transducers (TSI 8475) were sent digitally to a base station by means of wireless technology. WS-BU is the base station that receives the data from all sensors.

The received data is forwarded to a connected PC. Next, all readings have been displayed by the PC software, called SensorGraph. During operation the program is used to present and log measurement values. SensorGraph can also be used to retrieve logged values from disk and to present them on screen. Another standard feature is setting and handling of alarms from sensors. Any sensor can be programmed to monitor upper and lower boundaries and to generate an alarm when measurement values our outside these boundaries [12]. Simultaneously, SensorGraph can also be used to set and monitor alarm thresholds in addition to the boundaries in the sensors.

Figure 28. The base station, antenna WS-BU [12]

This sensing system called WiSensys developed by Wireless Value. WiSensys is a wireless sensing system with data logging capability. WiSensys offers a wireless infrastructure for connecting points of measurement with data evaluation centres. This tool could be connect wireless sensors that perform various measurements, for wireless temperature measurement, relative humidity, CO_2-content, energy consumption, analogue signals and contact. The working procedures of WiSensys is shown
in Figure 29.

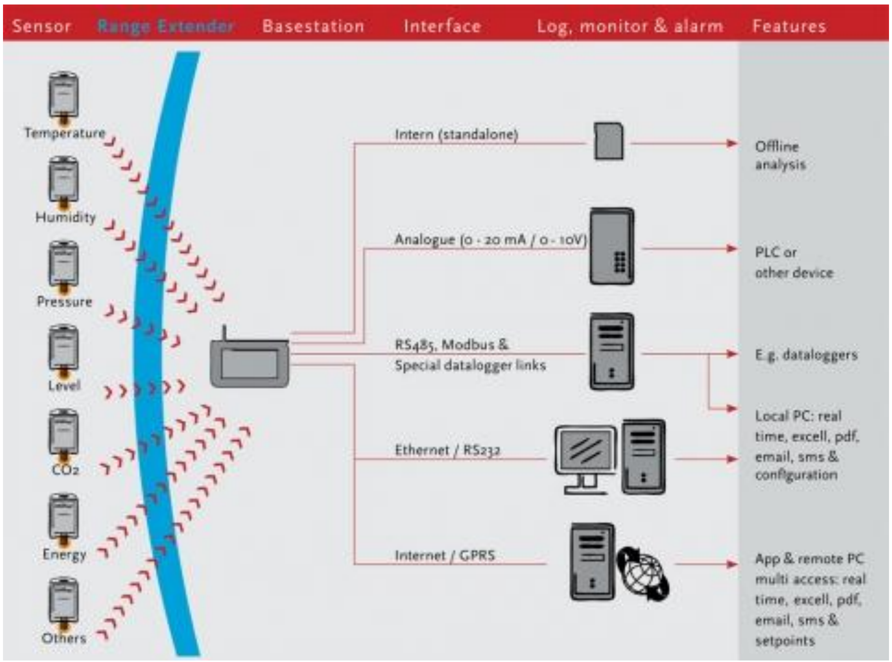


Figure 29.The working procedure of WiSensys

The measurement of velocity at one point took about 3 minutes, during this time the value of the velocity was measure 10 times, around every 20 seconds.

The measurement results of velocity was used to calculate the K factor. K is the dimensionless constant of the jet. To calculation used the following a formula:

$$\frac{U_m}{U_0} = \frac{K}{\sqrt{\frac{x}{h}}}$$

where:
U_m- is the local maximum velocity at a distance of x [m] downstream from the slot [m/s]
U_0 - is the supply velocity [m/s]
x - is the distance downstream from the slot [m]
h -is the slot height [m]

5. Results and discussion

5.1. Measurement results of CO_2 concentration

The CO_2 concentration was measured for the determined values the supply and exhaust airflow rate. Regarding to supply airflow rate, the set amount of air was in range between 72 m^3/h and 172 m^3/h. The measurements CO_2 concentration were carried out for 4 values:

- 78 m^3/h
- 117 m^3/h
- 147 m^3/h
- 173 m^3/h

To calculate the volume of supply air was used the measurement of internal velocity of jet. The sketch of the measurements points can be seen in Figure 10. Photos of location the supply air fan

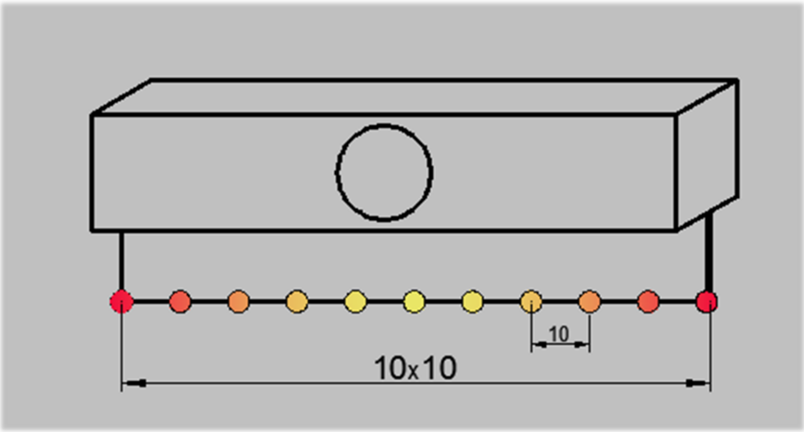


Figure 30. Sketch of measurements the internal velocity

The results of measurement the internal velocity by using VELOCICALC PLUS are shown below, in Table 1,2,3 and 4.

Table 1. The results of measurement average internal velocity equal to 2.47m/s

The measurements of initial velocity – case I				
No.	L	u_0	$u_{0\ avarege}$	The difference between the results of velocity and the average value of velocity
-	cm	m/s	m/s	%
1	0	2.50	2.47	1
2	10	2.41		-3
3	20	2.36		-5
4	30	2.28		-8
5	40	2.37		-4
6	50	2.56		3
7	60	2.53		2
8	70	2.49		1

9	80	2.54		3
10	90	2.57		4
11	100	2.61		5

Table 2. The results of measurement average internal velocity equal to 3.67 m/s

The measurements of initial velocity – case II				
No.	L	u_0	$u_{0\ \mathbf{avarege}}$	**The difference between the results of velocity and the average value of velocity**
-	cm	m/s	m/s	%
1	0	4.04	3.67	10
2	10	3.65		-1
3	20	3.40		-7
4	30	3.15		-14
5	40	3.33		-9
6	50	4.15		13
7	60	3.81		4
8	70	3.67		0
9	80	3.80		3
10	90	3.46		-6
11	100	3.95		8

Table 3. The results of measurement average internal velocity equal to 4.57 m/s

The measurements of initial velocity – case III				
No.	**L**	$\mathbf{u_0}$	$\mathbf{u_{0\ avarege}}$	**The difference between the results of velocity and the average value of velocity**
-	cm	m/s	m/s	%
1	0	4.90	4.57	7
2	10	4.60		1
3	20	4.23		-7
4	30	4.68		2
5	40	4.60		1
6	50	4.63		1
7	60	4.62		1
8	70	4.40		-4
9	80	4.32		-5
10	90	4.60		1
11	100	4.65		2

Table 4. The results of measurement average internal velocity equal to 5.20 m/s

The measurements of initial velocity – case IV				
No.	L	u_0	$u_{0\ avarege}$	The difference between the results of velocity and the average value of velocity
-	cm	m/s	m/s	%
1	0	6.16	5.20	18
2	10	5.31		2
3	20	4.43		-15
4	30	4.54		-13
5	40	4.76		-8
6	50	5.00		-4
7	60	5.15		-1
8	70	4.95		-5
9	80	5.30		2
10	90	5.45		5
11	100	6.16		18

Additionally, the volume of supply air was also measured by using balometer type TSI Model 8371 AccuBalance. The summary results of measurements of the supply airflow rate are shown in Table 5.

Table 5. The summary results of measurements of the supply airflow rate

Parameters	Internal velocity of jet (measurement of Velocicalc)	Effective area of slot jet	Supply airflow rate (by using Velocicalc)	Supply airflow rate (by using AccuBalance)	The average value of supply airflow rate
Units	m/s	m^2	m^3/h	m^3/h	m^3/h
1.	2.47	$0.009m^2$	80	75	78
2.	3.67		119	115	117
3.	4.57		148	146	147
4.	5.20		169	178	173

Subsequently, the volume of exhaust air was within the specified range, namely from 200 m^3/h to 435 m^3/h. The measurements were carried out for six different values such as:

- 220 m^3/h
- 250 m^3/h
- 310 m^3/h
- 375 m^3/h
- 400 m^3/h
- 435 m^3/h

To clarify and systematize, the measurement results of CO_2 concentration could be divided into subgroups :

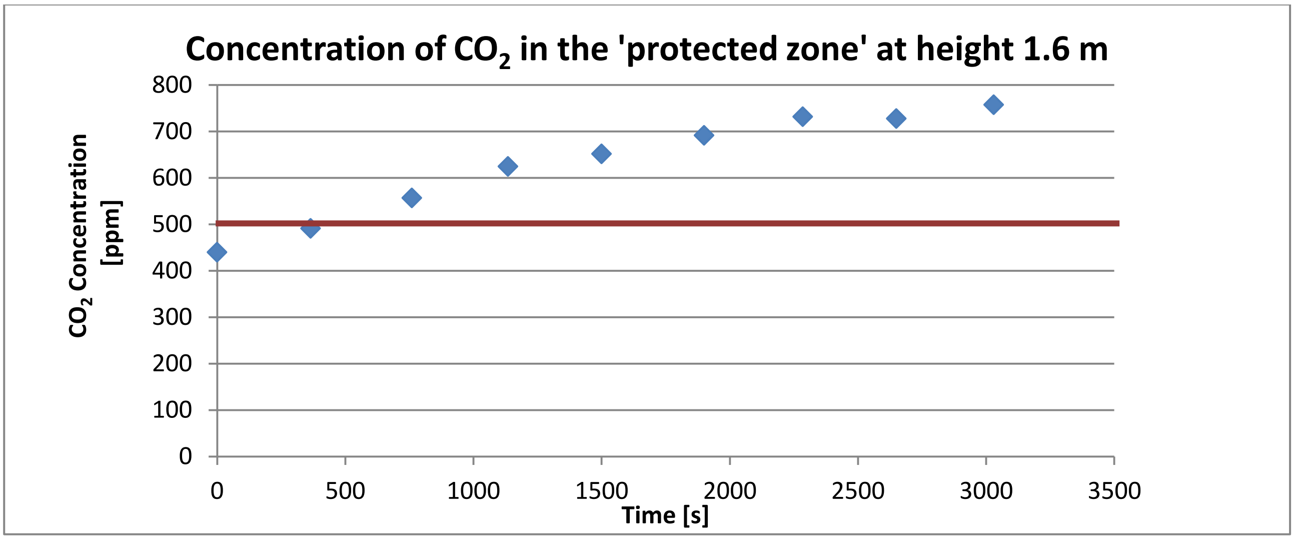
- a basic measurements which included:
    - measurement of CO_2 concentration in the background of the test room;

- measurement of CO_2 concentration with no activated the air curtain and exhaust air system which shows spread of tracer gas;
- measurement of CO_2 concentration to examine the dimensions of outlet opening;

- a main group of measurements include the cases of various supply or exhaust airflows rates
- an additional measurements which included:
  - measurement of CO_2 concentration with active the air curtain but without using the exhaust air system.

The CO_2 concentration in the background of the test room was measured each of day before the main measurements. The aim of measurement in the background of test room was to verify CO_2 concentration in ambient air and also check that measurement conditions are constant every day or there are any additional sources which increases of CO_2 concentration. During of conducting the experiment study, the CO_2 concentration of ambient air was always kept at a constant level about 441 ppm.

Next measurement was carried out without using the air curtain and exhaust air system. This result shows what is the actual values of CO_2 concentration when ventilation system does not work and how spreads the tracer gas. Moreover, the results will be useful while comparing the results obtained during operation.

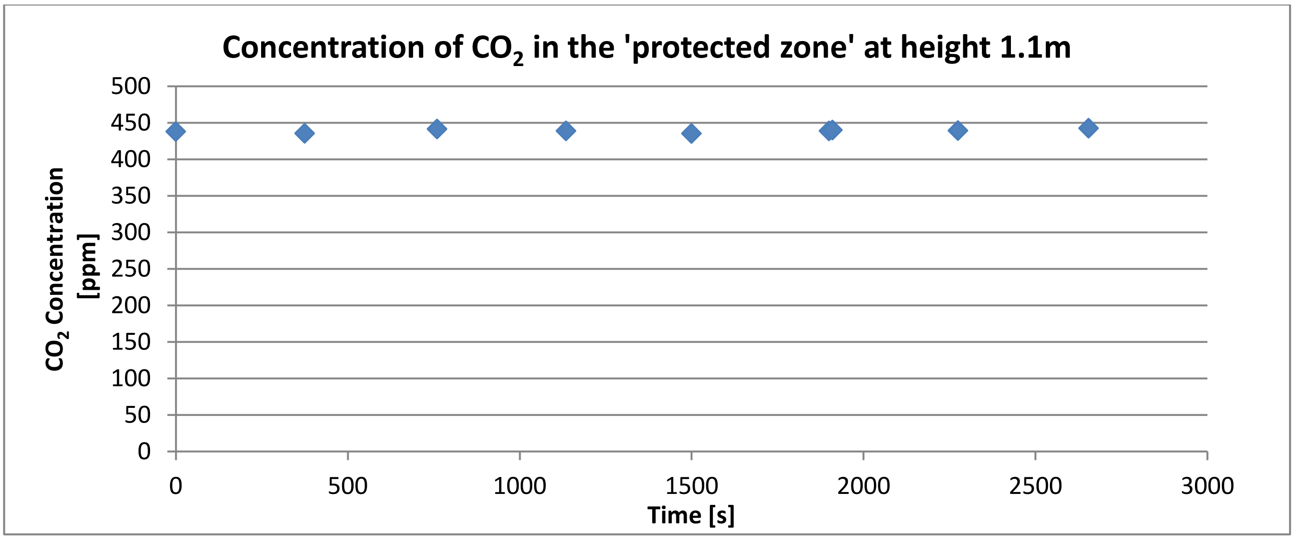


Graph 1. Concentration of CO_2 in the 'protected zone' at height 1.6 m in case without using the air curtain and exhaust air system

Table 6. Tabular listing of CO_2 concentration in the 'protected zone' at height 1.6 m in case without using the air curtain and exhaust air system

Concentration of CO_2 in the 'protected zone' at height 1.6 m			
No.	Time		CO_2 Concentration
	hh:mm:ss	s	ppm
1	14:53:06	0	439.75
2	14:59:11	365	491.07
3	15:05:46	760	556.71

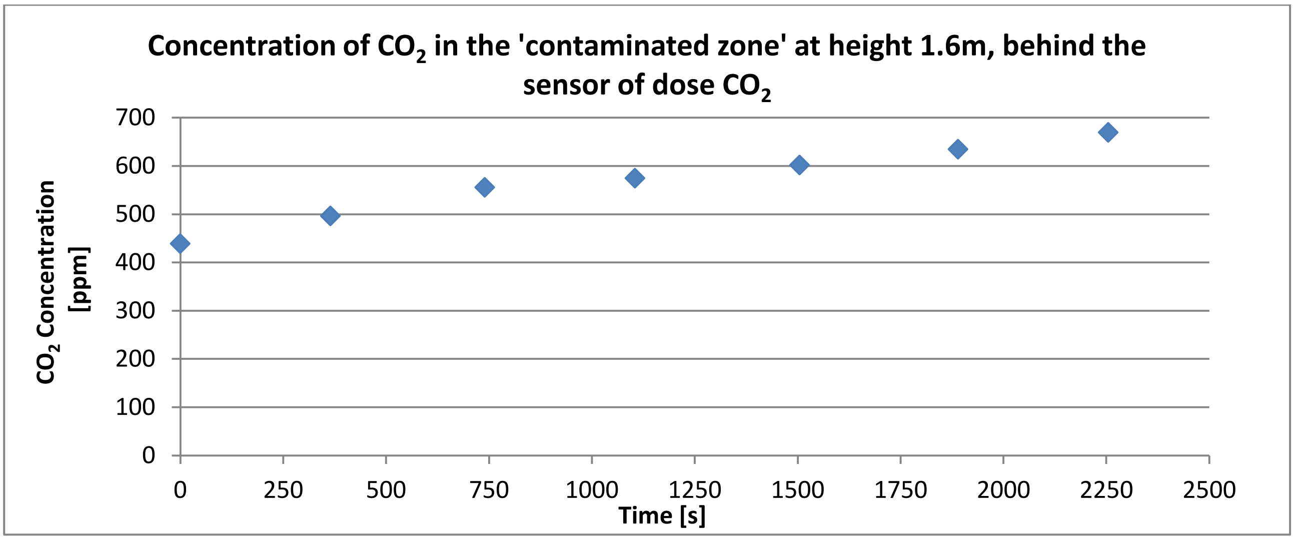
4	15:12:01	1135	624.56
5	15:18:06	1500	651.67
6	15:24:46	1900	691.53
7	15:31:11	2285	731.71
8	15:37:16	2650	727.67
9	15:43:36	3030	757.47



Graph 2. Concentration of CO_2 in the 'protected zone' at height 1.1m in case without using the air curtain and exhaust air system

Table 7. Tabular listing of CO_2 concentration in the 'protected zone' at height 1.1 m in case without using the air curtain and exhaust air system

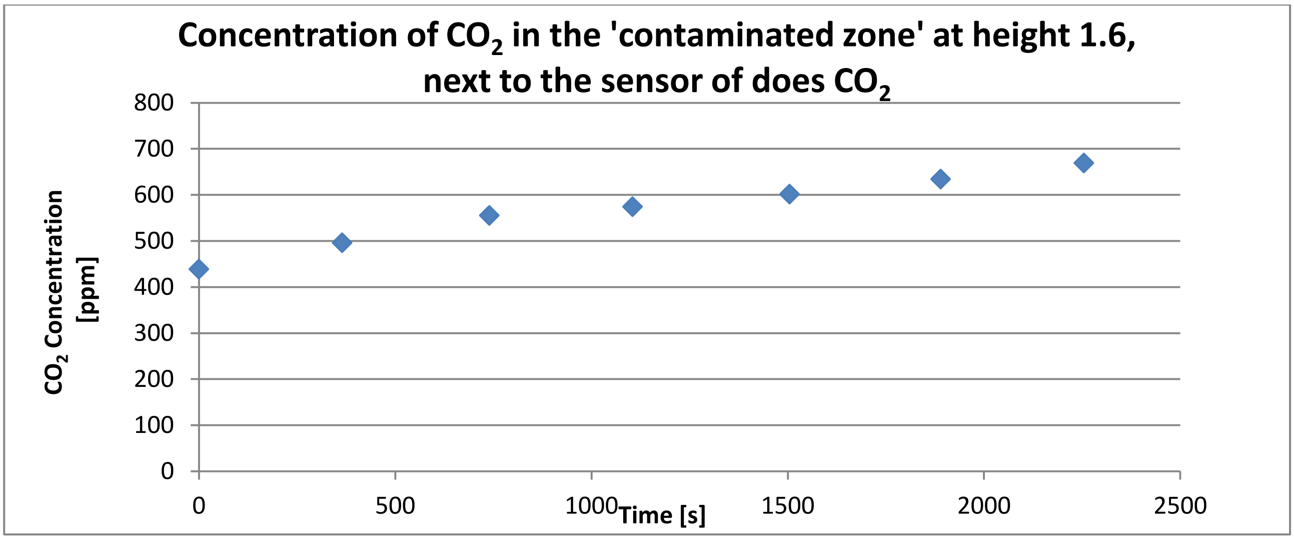
Concentration of CO_2 in the 'protected zone' at height 1.1m			
No.	Time		CO_2 Concentration
	hh:mm:ss	s	ppm
1	14:54:11	0	438.21
2	15:00:21	375	435.70
3	15:06:46	760	441.63
4	15:13:01	1135	439.10
5	15:19:06	1500	435.52
6	15:25:46	1900	439.05
7	15:32:11	1910	440.24
8	15:38:16	2275	439.50
9	15:44:36	2655	442.74



Graph 3. Concentration of CO_2 in the 'contaminated zone' at height 1.6m, behind the sensor of dose CO_2 in case without using the air curtain and exhaust air system

Table 8. Tabular listing of CO_2 concentration in the 'contaminated zone' at height 1.6m, behind the sensor of dose CO_2 in case without using the air curtain and exhaust air system

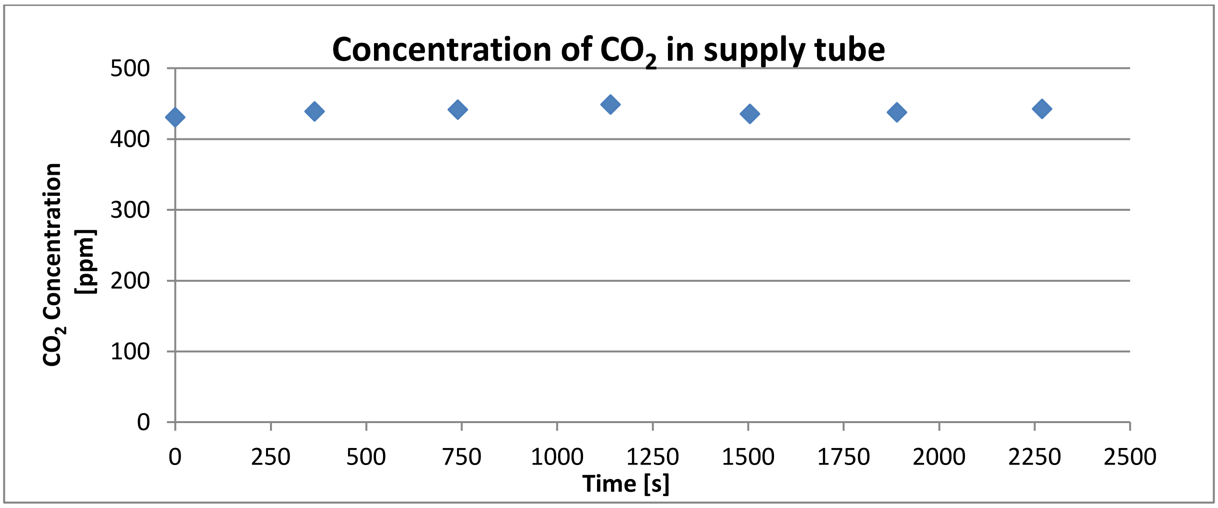
Concentration of CO_2 in the 'contaminated zone' at height 1.6m, behind the sensor of dose CO_2			
No.	Time		CO_2 Concentration
	hh:mm:ss	s	ppm
1	15:01:41	0	439.01
2	15:07:46	365	496.37
3	15:14:01	740	555.62
4	15:20:06	1105	574.58
5	15:26:46	1505	601.88
6	15:33:11	1890	634.59
7	15:39:16	2255	669.49
8	15:35:21	2620	701.22



Graph 4. Concentration of CO_2 in the 'contaminated zone' at height 1.6, next to the sensor of does CO_2 in case without using the air curtain and exhaust air system

Table 9. Tabular listing of CO_2 concentration in the 'contaminated zone' at height 1.6, next to the sensor of does CO_2 in case without using the air curtain and exhaust air system

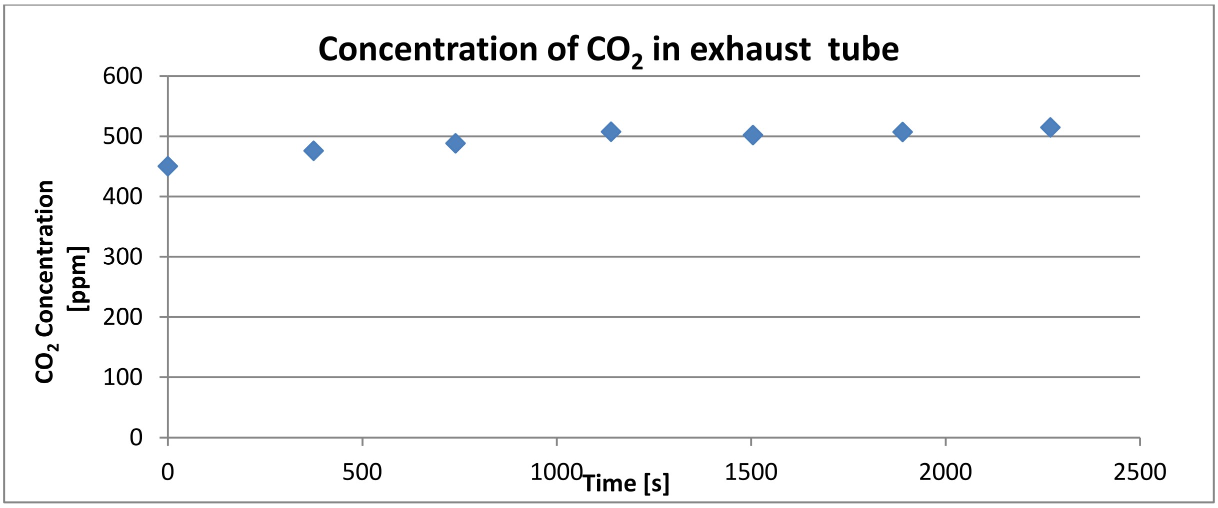
Concentration of CO_2 in the 'contaminated zone' at height 1.6 m, next to the sensor of dose CO_2			
No.	Time		CO_2 Concentration
	hh:mm:ss	s	ppm
1	15:02:46	0	28510.0
2	15:08:51	365	32150.0
3	15:15:06	740	32710.0
4	15:21:41	1135	33230.0
5	15:27:51	1505	23990.0
6	15:34:16	1890	30530.0
7	15:40:21	2255	33080.0



Graph 5. Concentration of CO_2 in supply tube in case without using the air curtain and exhaust air sy stem

Table 10. Tabular listing of CO_2 concentration in supply tube in case without using the air curtain and exhaust air system

Concentration of CO_2 in sypply tube			
No.	Time		CO2 Concentration
	hh:mm:ss	s	ppm
1	15:03:41	0	430.96
2	15:09:46	365	439.21
3	15:16:01	740	441.74
4	15:22:41	1140	448.98
5	15:28:46	1505	435.74
6	15:35:11	1890	437.95
7	15:41:31	2270	442.81



Graph 6. Concentration of CO_2 in exhaust tube in case without using the air curtain and exhaust air system

Table 11. Tabular listing of CO_2 concentration in exhaust tube in case without using the air curtain and exhaust air system

Concentration of CO_2 in exhaust tube			
No.	Time		CO2 Concentration
	hh:mm:ss	s	ppm
1	15:04:46	0	450.33
2	15:11:01	375	475.96
3	15:17:06	740	488.36
4	15:23:46	1140	507.58
5	15:29:51	1505	502.08
6	15:36:16	1890	507.20
7	15:42:36	2270	514.78

As shows the results of case without using the air curtain, dosed tracer gas quickly spreads on both zones. The lack of ventilation system causes to significant increase of the CO_2 concentration in protected zone and contaminated zone at height 1.6 m. In protected zone the concentration was reached values 757 ppm. The low concentration of CO_2 is kept in protected zone at 1.1m. This may be due dosing gas at the height of 1.6 m. The results of this case shows that the indoor pollution transfers very fast and are a major threat to resident people. This example shows how necessary it is to perform the protect zone ventilation to reduce personal exposure to indoor pollution.

Furthermore, very importance factor which also influence to possibility protect the select zone is effective area of a outlet opening. In order to the ventilation system would be functional, useful and easier to implement to reception space in hospital or in health facilities, the dimensions of outlet air nozzle should be minimum. Thus, were carried out multiple measurements in order to examine the size of outlet opening. During the study found that the most suitable width of exhaust opening is equal to 4 cm. Therefore, the recommended dimensions of outlet opening are equal to 0.04 m x 1.0 m. After presentation the results of main measurement will be show the example of case with dimension of outlet exhaust which are insufficient to separate two zones.

The main measurement consider of the fifteen cases. For each case created six tables with the reading from the Gas-Monitor - Multipoint Sampler and Doser Type 1303 and graphs which illustrate the concentration level of contaminant in the protected and polluted zone and the spread of CO_2, as indoor pollutant source. Each of table or graph presents the results from another measurement's point. Two case of sampling points such as:

- a probe placed in supply tube,
- a probe placed immediately to the dosing wire of tracer gas,

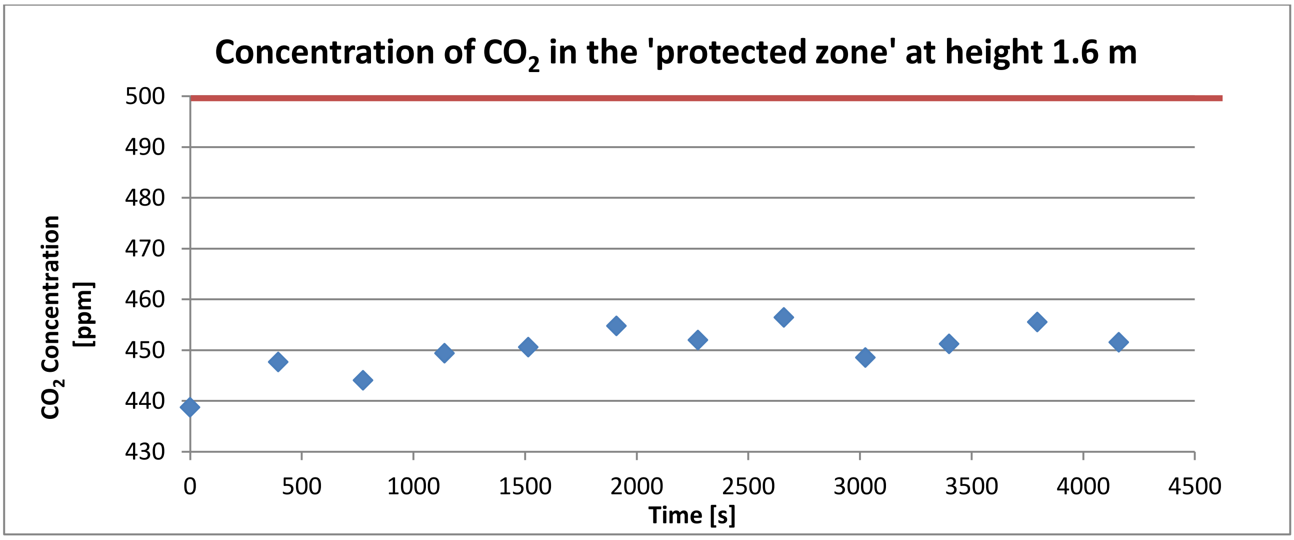
will be the object of smaller discussion. In fact, the measurements of concentration in this space have a monitoring function, namely validate the operation of the CO_2 dosing system or inform that the external sources of contamination does not affect the measurements in the test room. The concentration in this points should be uniform and kept on the same level.

Prior to the presentation of results, will be reported the schema of operation during the measurement. Thus, each series of measurements were taken under different conditions, namely various values volume of supply and exhaust air. Every following measurement series, the amount of exhaust air was reduced. Measurements continued until the moment when the plane jet does not prevent the transmission of pollutants from the polluted zone to the protected zone. To clarify, first series of measurement will be contained a presentation and a discussion of results and also a description of the method carried out the research.

Table 6. Experimental series no. 1:

Experimental series no. 1 - Measurement conditions				
Number of case	**Jet supply velocity (m/s)**	**Volume of supply air [m^3/h]**	**Volume of exhaust air [m^3/h]**	**Dimensions of outlet opening [m]**
1.1	5.20	173	435	0.04x1.00
1.2	5.20	173	400	0.04x1.00
1.3	5.20	173	375	0.04x1.00

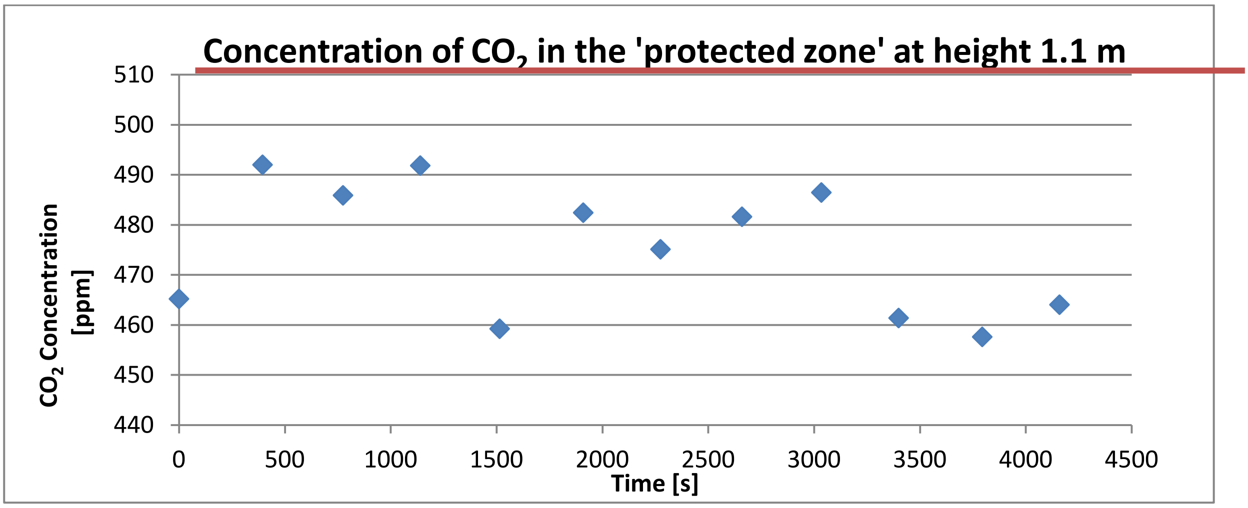
- **Case No. 1.1**



Graph 7. Concentration of CO_2 in the 'protected zone' at height 1.6 m - series no. 1 case 1.1

Table 12. Tabular listing of CO_2 concentration in the 'protected zone' at height 1.6 m - series no. 1 case 1.1

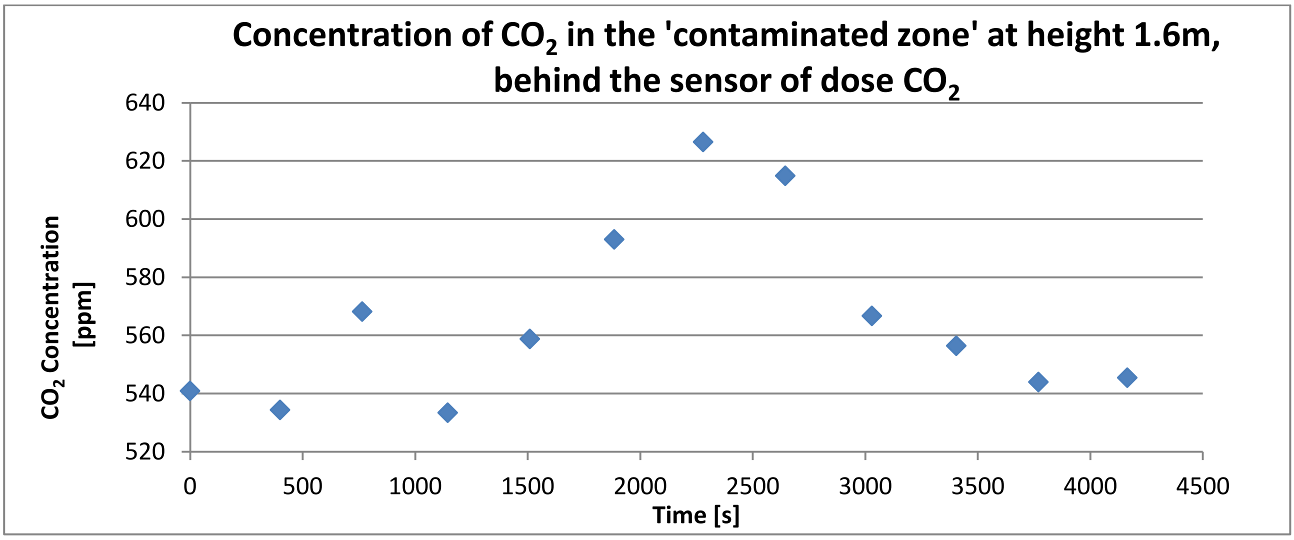
Concentration of CO_2 in the 'protected zone' at height 1.6 m			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	03:46:05	0	438.78
2	03:52:40	395	447.71
3	03:59:00	775	444.1
4	04:05:05	1140	449.43
5	04:11:20	1515	450.63
6	04:17:55	1910	454.81
7	04:24:00	2275	452.03
8	04:30:25	2660	456.48
9	04:36:30	3025	448.58
10	04:42:45	3400	451.27
11	04:49:20	3795	455.58
12	04:55:25	4160	451.59



Graph 8. Concentration of CO_2 in the 'protected zone' at height 1.1 m - series no. 1 case 1.1

Table 13. Tabular listing of CO_2 concentration CO_2 in the 'protected zone' at height 1.1 m - series no. 1 case 1.1

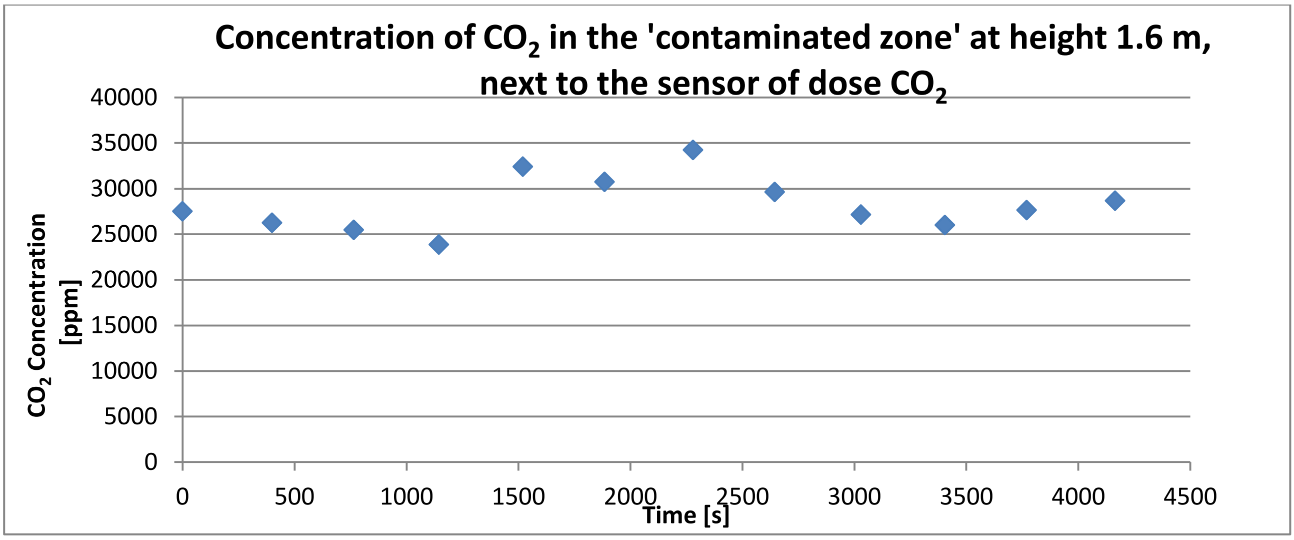
Concentration of CO_2 in the 'protected zone' at height 1.1 m			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	03:47:05	0.00	465.23
2	03:53:40	395.00	492.03
3	04:00:00	775.00	485.92
4	04:06:05	1140.00	491.87
5	04:12:20	1515.00	459.26
6	04:18:55	1910.00	482.46
7	04:25:00	2275.00	475.14
8	04:31:25	2660.00	481.65
9	04:37:40	3035.00	486.49
10	04:43:45	3400.00	461.41
11	04:50:20	3795.00	457.64
12	04:56:25	4160.00	464.07



Graph 9. Concentration of CO_2 in the 'contaminated zone' at height 1.6m, behind the sensor of dose CO_2 -series no. 1 case 1.1

Table 14. Tabular listing of CO_2 concentration in the 'contaminated zone' at height 1.6m, behind the sensor of dose CO_2 - series no. 1 case 1.1

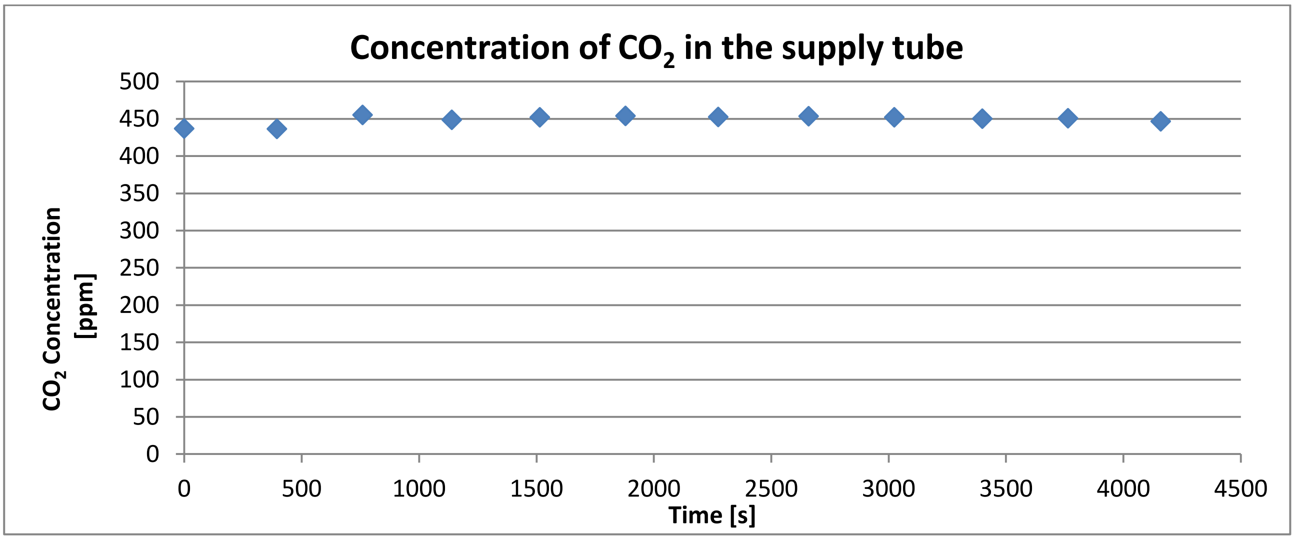
Contaminated zone – 1.6m behind the sensor of dose CO_2			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	03:41:55	0.00	540.97
2	03:48:35	400.00	534.44
3	03:54:40	765.00	568.25
4	04:01:00	1145.00	533.48
5	04:07:05	1510.00	558.84
6	04:13:20	1885.00	593.07
7	04:19:55	2280.00	626.58
8	04:26:00	2645.00	614.94
9	04:32:25	3030.00	566.77
10	04:38:40	3405.00	556.49
11	04:44:45	3770.00	544.03
12	04:51:20	4165.00	545.52



Graph 10. Concentration of CO_2 in the 'contaminated zone' at height 1.6 m, next to the sensor of dose CO_2 –series no. 1 case no. 1.1

Table 15. Tabular listing of CO_2 concentration in the 'contaminated zone' at height 1.6 m, next to the sensor of dose CO_2 – series no. 1 case no. 1.1

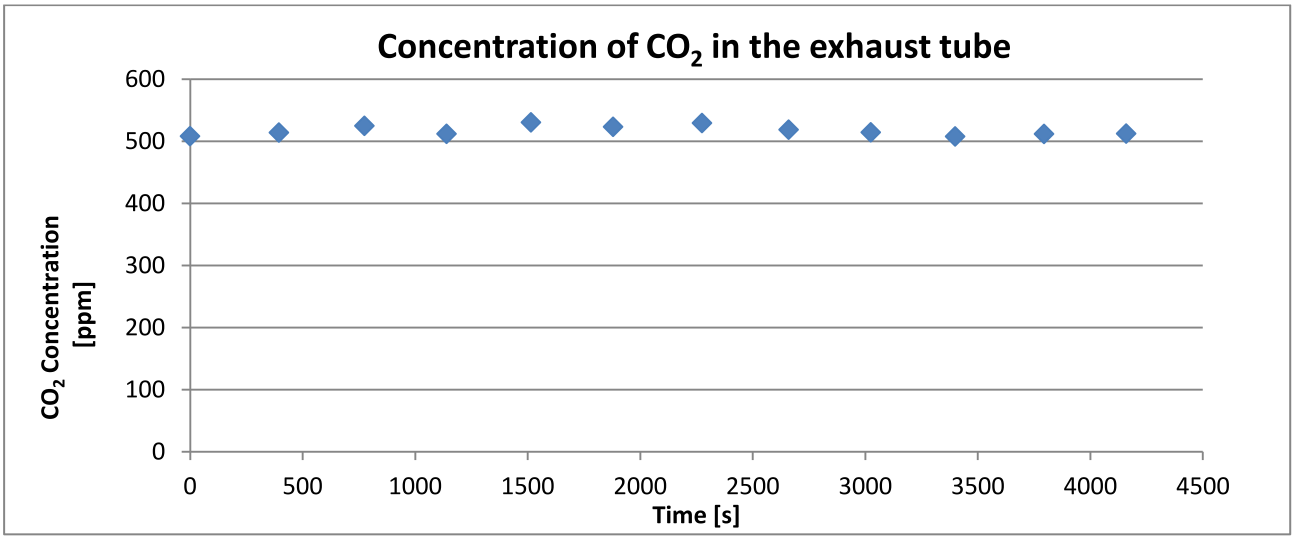
contaminated zone -1.6m next to the sensor of dose CO_2			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	03:42:55	0	27530
2	03:49:35	400	26270
3	03:55:40	765	25490
4	04:02:00	1145	23880
5	04:08:15	1520	32430
6	04:14:20	1885	30760
7	04:20:55	2280	34260
8	04:27:00	2645	29650
9	04:33:25	3030	27170
10	04:39:40	3405	26020
11	04:45:45	3770	27660
12	04:52:20	4165	28690



Graph 11. Concentration of CO_2 in the supply tube – series no. 1 case 1.1

Table 16. Tabular listing of CO_2 concentration in the supply tube – series no. 1 case 1.1

Concentration of CO_2 in the supply tube			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	03:44:00	0.00	437.17
2	03:50:35	395.00	436.72
3	03:56:40	760.00	455.45
4	04:03:00	1140.00	448.89
5	04:09:15	1515.00	452.28
6	04:15:20	1880.00	454.18
7	04:21:55	2275.00	452.75
8	04:28:20	2660.00	453.73
9	04:34:25	3025.00	452.29
10	04:40:40	3400.00	450.46
11	04:46:45	3765.00	451.02
12	04:53:20	4160.00	446.87

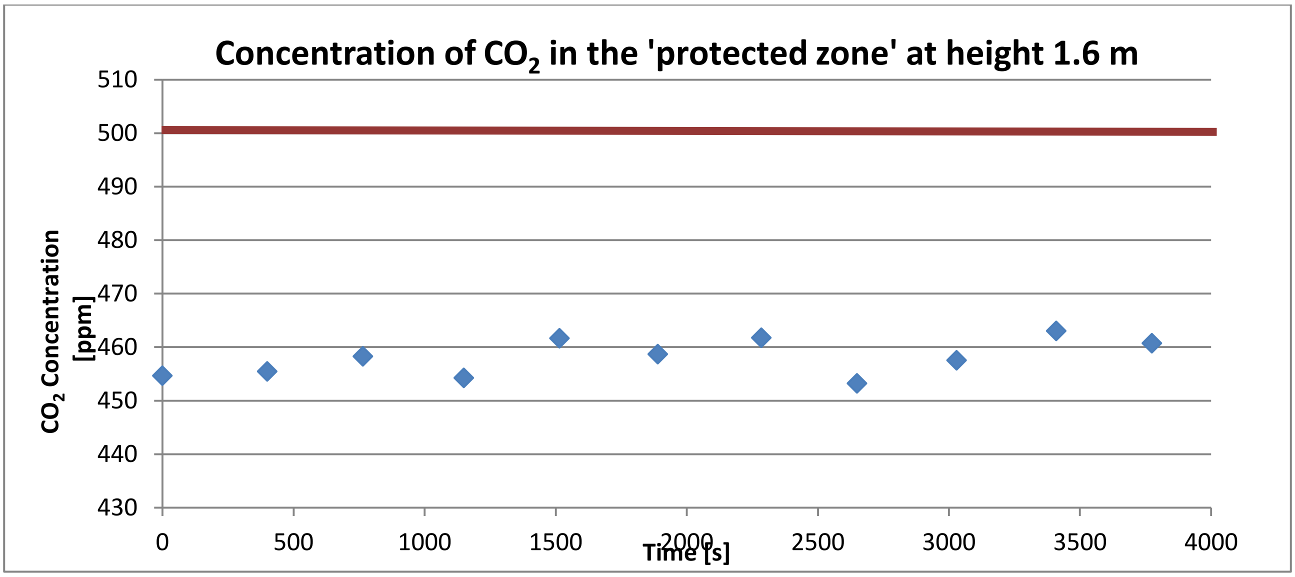


Graph 12. Concentration of CO_2 in the exhaust tube – series no. 1 case no. 1.1

Table 17. Tabular listing of CO_2 concentration in the exhaust tube – series no. 1 case no. 1.1

Concentration of CO_2 in the exhaust tube			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	03:45:05	0	508.47
2	03:51:40	395	514.28
3	03:58:00	775	525.13
4	04:04:05	1140	512.24
5	04:10:20	1515	530.71
6	04:16:25	1880	523.52
7	04:23:00	2275	529.65
8	04:29:25	2660	518.93
9	04:35:30	3025	514.63
10	04:41:45	3400	508.05
11	04:48:20	3795	512.09
12	04:54:25	4160	512.64

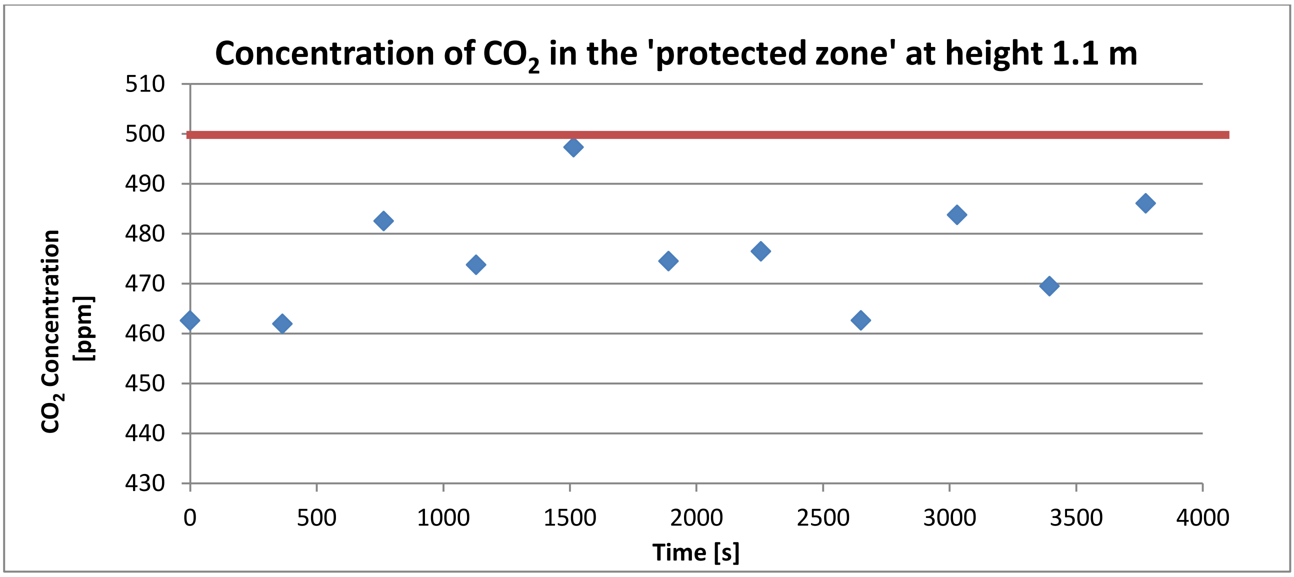
- **Case No. 1.2**



Graph 13. Concentration of CO_2 in the 'protected zone' at height 1.6 m – series no. 1 case no. 1.2

Table 18. Tabular listing of CO_2 concentration in the 'protected zone' at height 1.6 m – series no. 1 case no. 1.2

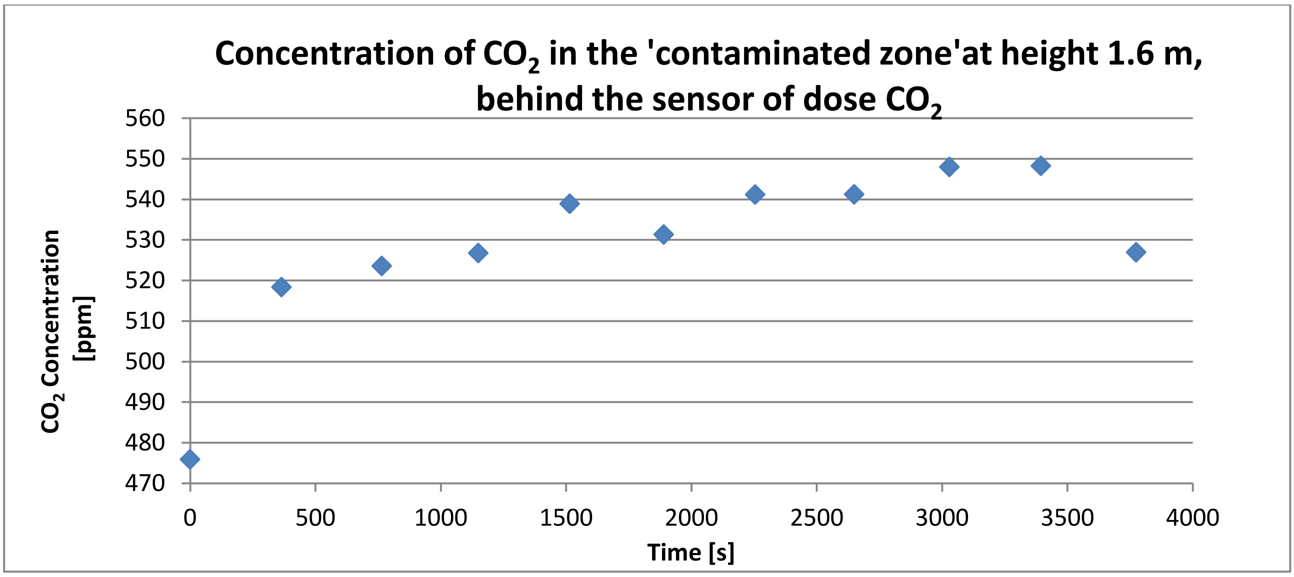
Concentration of CO_2 in the 'protected zone' at height 1.6 m			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	09:42:36	0	454.69
2	09:49:16	400	455.49
3	09:55:21	765	458.31
4	10:01:46	1150	454.28
5	10:07:51	1515	461.69
6	10:14:06	1890	458.72
7	10:20:41	2285	461.79
8	10:26:46	2650	453.26
9	10:33:06	3030	457.57
10	10:39:26	3410	463.06
11	10:45:31	3775	460.76



Graph 14. Concentration of CO_2 in the 'protected zone' at height 1.1 m – series no.1 case 1.2

Table 19. Tabular listing of CO_2 concentration in the 'protected zone' at height 1.1 m – series no.1 case 1.2

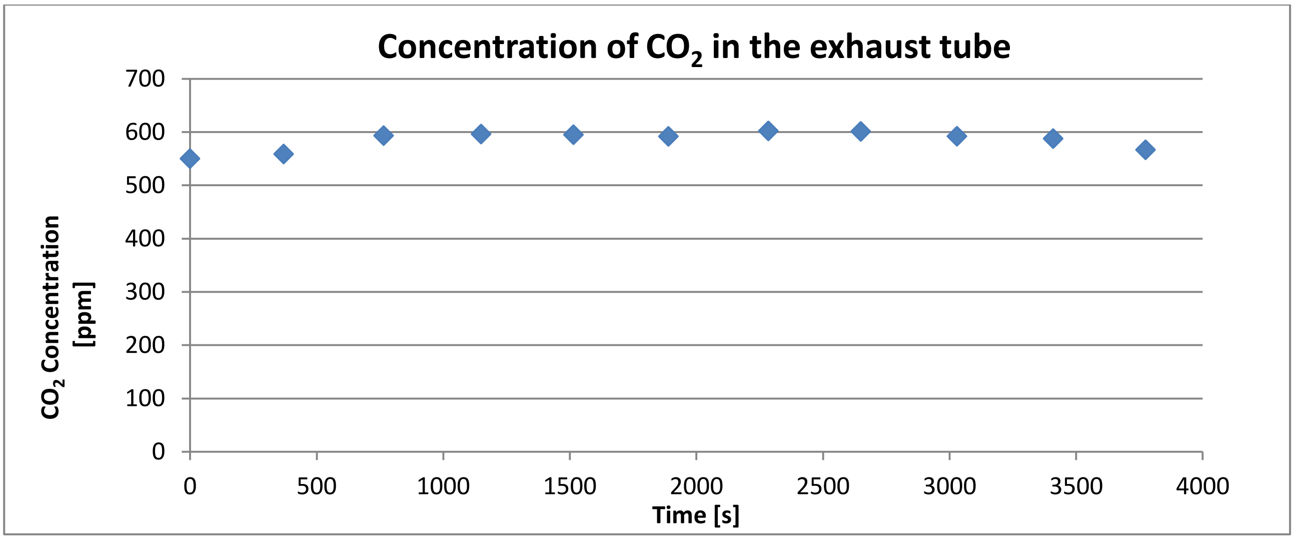
Concentration of CO_2 in the 'protected zone' at height 1.1 m			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	09:38:31	0	462.63
2	09:44:36	365	461.97
3	09:51:16	765	482.57
4	09:57:21	1130	473.8
5	10:03:46	1515	497.37
6	10:10:01	1890	474.54
7	10:16:06	2255	476.5
8	10:22:41	2650	462.66
9	10:29:01	3030	483.81
10	10:35:06	3395	469.52
11	10:41:26	3775	486.12



Graph 15. Concentration of CO_2 in the 'contaminated zone at height 1.6 m, behind the sensor of dose CO_2 – series no. 1 case no. 1.2

Table 20. Tabular listing of CO_2 concentration in the 'contaminated zone at height 1.6 m, behind the sensor of dose CO_2 – series no. 1 case no. 1.2

contaminated zone -1.6m behind the sensor of dose CO2			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	09:39:31	0.00	475.91
2	09:45:36	365.00	518.40
3	09:52:16	765.00	523.61
4	09:58:41	1150.00	526.80
5	10:04:46	1515.00	538.95
6	10:11:01	1890.00	531.36
7	10:17:06	2255.00	541.22
8	10:23:41	2650.00	541.27
9	10:30:01	3030.00	548.02
10	10:36:06	3395.00	548.30
11	10:42:26	3775.00	526.98



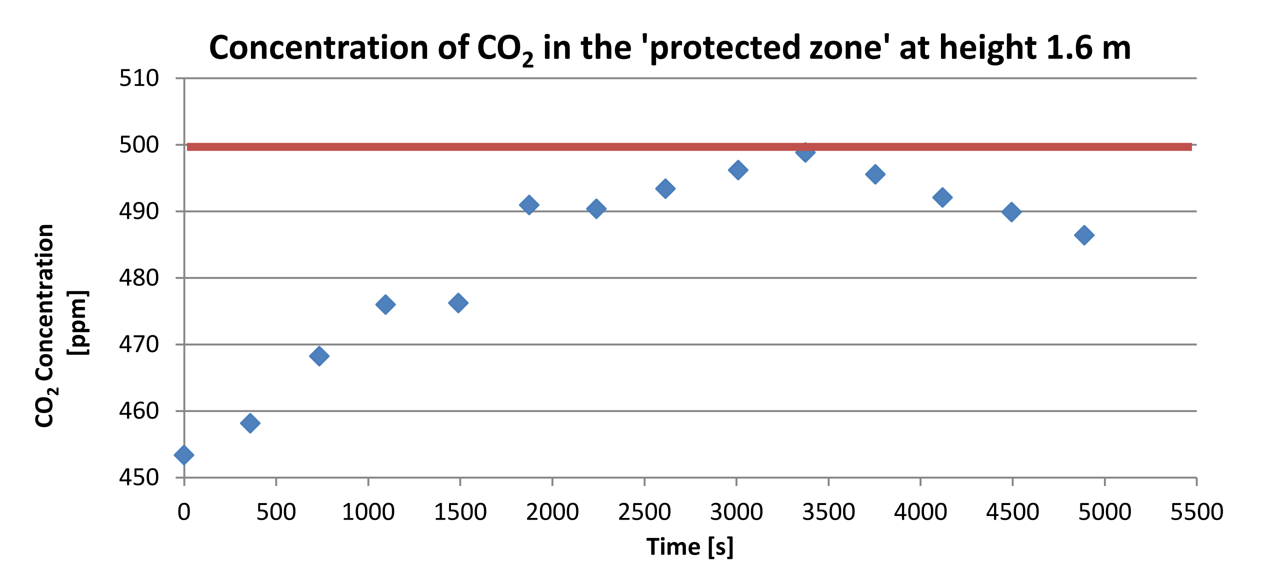
Graph 16. Concentration of CO_2 in the exhaust tube – series no. 1 case no. 1.2

Table 21. Tabular listing of CO_2 concentration in the exhaust tube – series no. 1 case no. 1.2

Concentration of CO_2 in the exhaust tube			
No.	Time		CO2 concentration
	hh:mm:ss	s	ppm
1	09:41:31	0	550.42
2	09:47:41	370	559.01
3	09:54:16	765	593.56
4	10:00:41	1150	596.51
5	10:06:46	1515	595.25
6	10:13:01	1890	592.14
7	10:19:36	2285	602.42
8	10:25:41	2650	601.49
9	10:32:01	3030	592.36
10	10:38:21	3410	587.98
11	10:44:26	3775	566.94

As shown the measurement results from case no. 1.1 and 1.2 the results are closely resembling, namely the average CO_2 concentration in protected zone at height 1.6 is kept at the level 450 ppm and at height 1.1 is about 475 ppm for each cases. Thus, in both of cases these ventilation system using a plane jet is able to separate the room into two zones with a different concentration level of contaminant. However it had to be examined if it is possible to reduce the values of exhaust airflow at which the selected zone will still be protected from transferred pollution. Thus the next measurement – case no. 1.3 was carried out. As can been seen, only for series no.1 case no. 1.1 are presented the results of sampling points in supply tube and immediately to CO_2 dosing wire. The results have been presented only in this cases in order to avoid duplication of results. In this study the results of this measurement points are almost the same and the shape of graphs are extremely close.

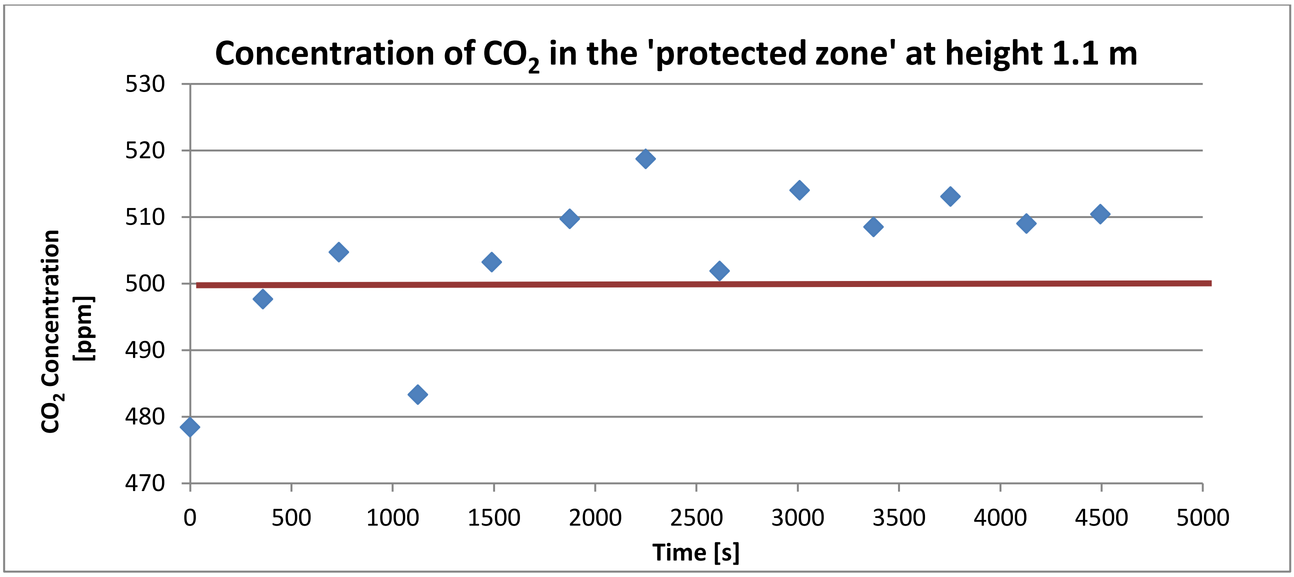
- **Case No. 1.3**



Graph 17. Concentration of CO_2 in the 'protected zone' at height 1.6 m – series no. 1 case no. 1.3

Table 22. Tabular listing of CO_2 concentration in the 'protected zone' at height 1.6 m – series no. 1 case no. 1.3

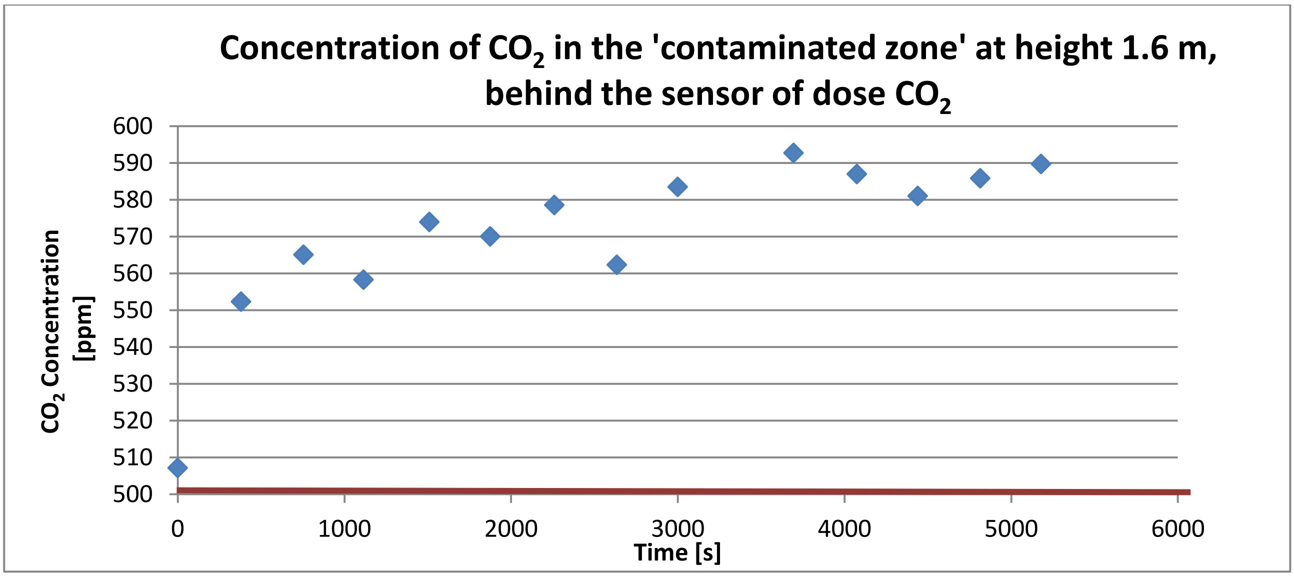
Concentration of CO_2 in the 'protected zone' at height 1.6 m			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	09:19:00	0	453.37
2	09:25:00	360	458.15
3	09:31:15	735	468.24
4	09:37:15	1095	475.99
5	09:43:50	1490	476.23
6	09:50:15	1875	490.96
7	09:56:20	2240	490.39
8	10:02:35	2615	493.41
9	10:09:10	3010	496.21
10	10:15:15	3375	498.86
11	10:21:35	3755	495.57
12	10:27:40	4120	492.09
13	10:33:55	4495	489.90
14	10:40:30	4890	486.42



Graph 18. Concentration of CO_2 in the 'protected zone' at height 1.1 m – series no. 1 case no 1.3

Table 23. Tabular listing of CO_2 concentration in the 'protected zone' at height 1.1 m – series no. 1 case no 1.3

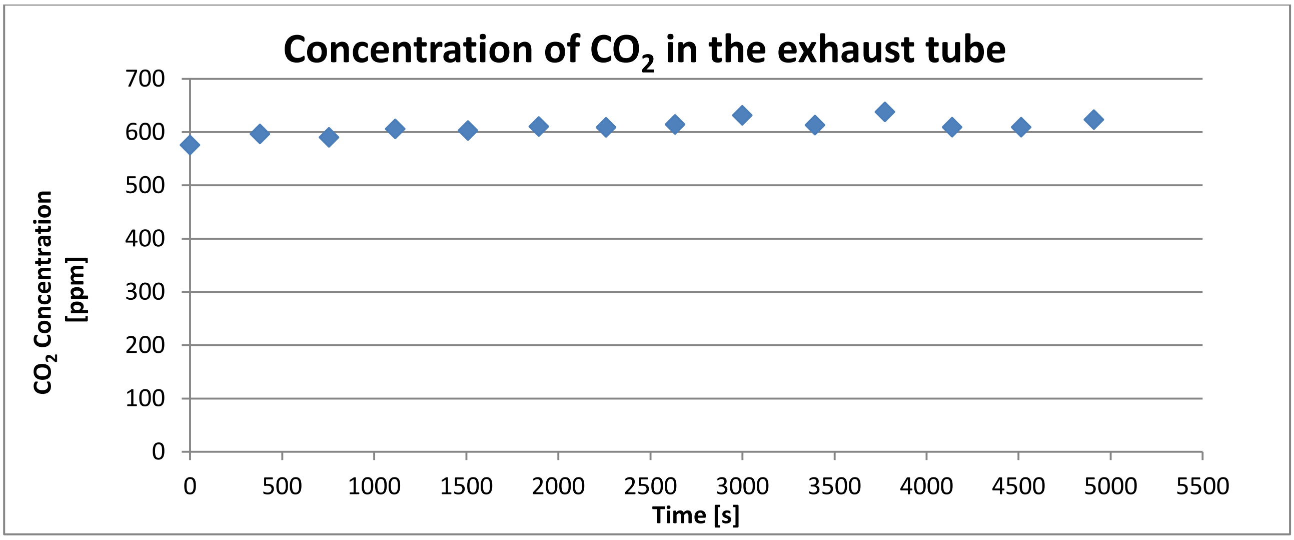
Concentration of CO_2 in the 'protected zone' at height 1.1 m			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	09:21:00	0	478.44
2	09:27:00	360	497.69
3	09:33:15	735	504.75
4	09:39:45	1125	483.33
5	09:45:50	1490	503.25
6	09:52:15	1875	509.76
7	09:58:30	2250	518.77
8	10:04:35	2615	501.92
9	10:11:10	3010	514.05
10	10:17:15	3375	508.54
11	10:23:35	3755	513.11
12	10:29:50	4130	509.05
13	10:35:55	4495	510.46



Graph 19. Concentration of CO_2 in the 'contaminated zone' at height 1.6 m, behind the sensor of dose CO_2 – series no. 1 case no. 1.3

Table 24. Tabular listing of CO_2 concentration in the 'contaminated zone' at height 1.6 m, behind the sensor of dose CO_2 – series no. 1 case no. 1.3

Contaminated zone -1.6m behind the sensor of dose CO2			
No.	Time		CO2 concentration
	hh:mm:ss	s	ppm
1	09:15:35	0	507.20
2	09:21:55	380	552.39
3	09:28:10	755	565.13
4	09:34:10	1115	558.35
5	09:40:45	1510	574.04
6	09:46:50	1875	570.11
7	09:53:15	2260	578.63
8	09:59:30	2635	562.40
9	10:05:35	3000	583.56
10	10:12:10	3695	592.79
11	10:18:30	4075	587.05
12	10:24:35	4440	581.10
13	10:30:50	4815	585.91
14	10:36:55	5180	589.79



Graph 20. Concentration of CO_2 in the exhaust tube – series no. 1 case no. 1.3

Table 25. Tabular listing of CO_2 concentration in the exhaust tube – series no. 1 case no. 1.3

Concentration of CO_2 in the exhaust tube			
No.	Time		CO2 concentration
	hh:mm:ss	s	ppm
1	09:17:35	0	575.90
2	09:23:55	380	596.73
3	09:30:10	755	590.33
4	09:36:10	1115	606.19
5	09:42:45	1510	603.07
6	09:49:10	1895	610.67
7	09:55:15	2260	609.09
8	10:01:30	2635	614.55
9	10:07:35	3000	631.67
10	10:14:10	3395	613.35
11	10:20:30	3775	638.12
12	10:26:35	4140	609.41
13	10:32:50	4515	609.41
14	10:39:25	4910	623.57

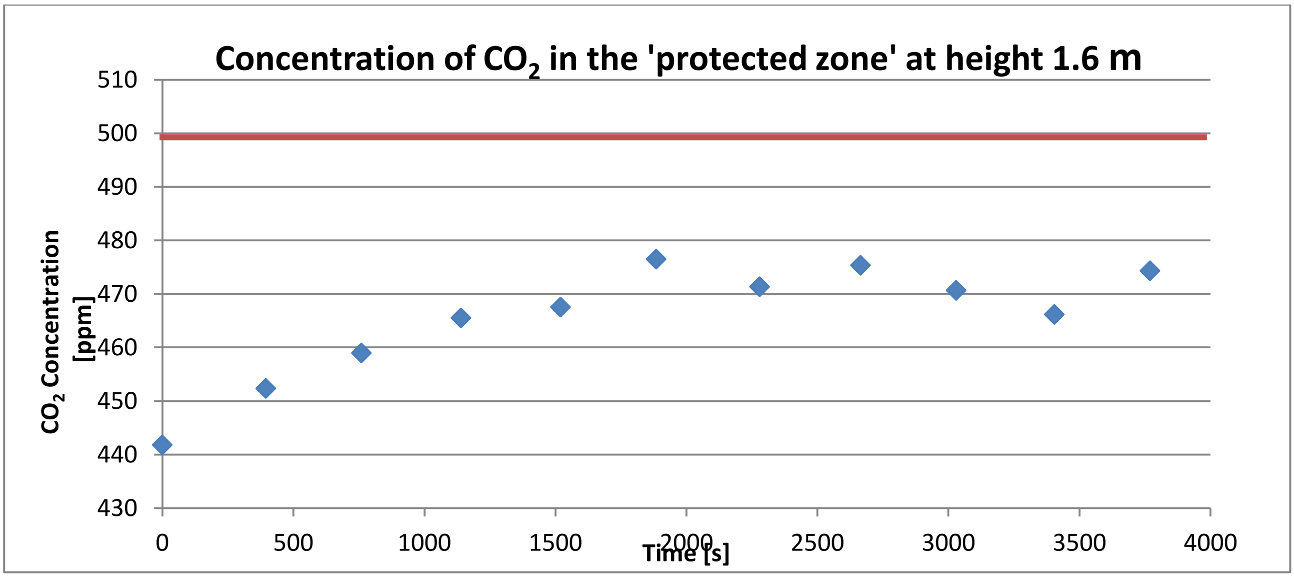
Case no 1.3 is example of finding the approximate edge/reach where after crossing this border, the air curtain will be not able to separate two zones. As shown Graph 18 the limit of CO_2 concentration was exceeded, almost all readings are higher than 500 ppm. The CO_2 concentration in protected zone at height 1.6 is also high, near to limit and significantly differs from the concentration values in case no. 1.2 at the same measurement point. In case 1.2 the average concentration was kept at the level 450 ppm, whereas in case is equal to 483 ppm. After the completing this measurement and analyzing it, found that this series could be completed. Decreasing the volume of exhaust air would result in increase of contamination in protected zone.

Hence, in series no.1 the most effective procedure with using the air curtain to protect the workplace in reception space and reducing the exposure occupants to adverse effect spreading of contaminations is case 1.2.

Table 26. Experimental series No. 2

Experimental series No. 2 - Measurement conditions				
Number of case	Jet supply velocity (m/s)	Volume of supply air [m3/h]	Volume of exhaust air [m3/h]	Dimensions of outlet opening [m]
2.1	4.57	147	400	0.04x1.00
2.2	4.57	147	375	0.04x1.00

- **Case No 2.1**

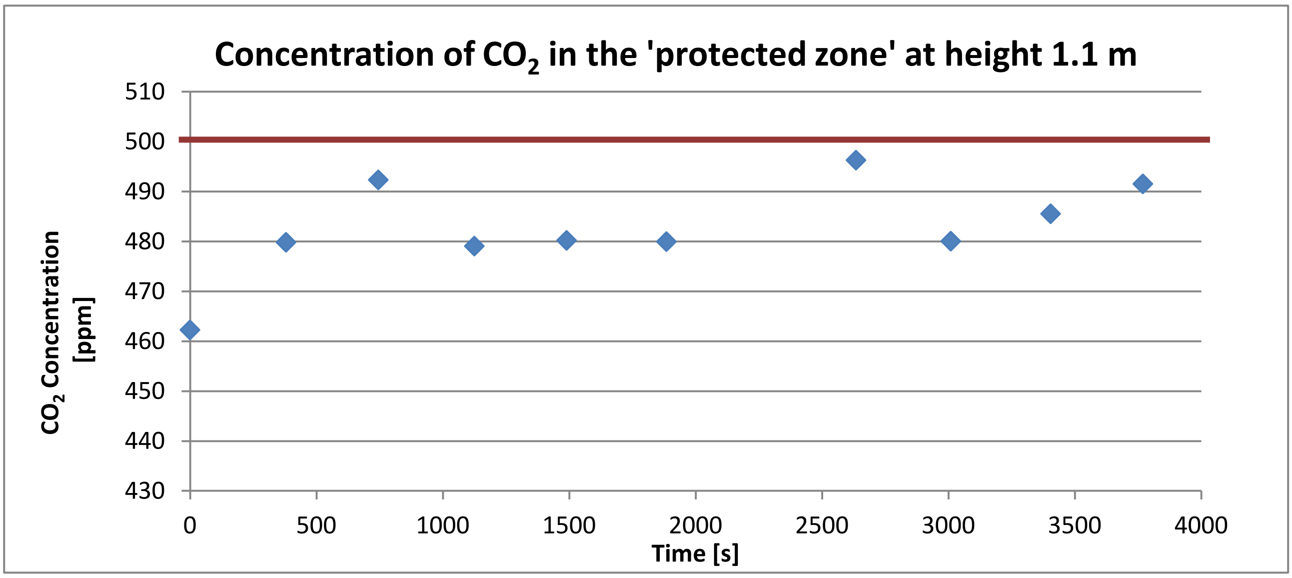


Graph 21. Concentration of CO_2 in the 'protected zone' at height 1.6 m –series no. 2 case no. 2.1

Table 27. Tabular listing of CO_2 concentration in the 'protected zone' at height 1.6 m –series no. 2 case no. 2.1

Concentration of CO_2 in the 'protected zone' at height 1.6 m			
No.	Time		CO2 concentration
	hh:mm:ss	s	ppm
1	06:51:02	0	441.84
2	06:57:37	395	452.39
3	07:03:42	760	459.00
4	07:10:02	1140	465.55
5	07:16:22	1520	467.57
6	07:22:27	1885	476.53
7	07:29:02	2280	471.37

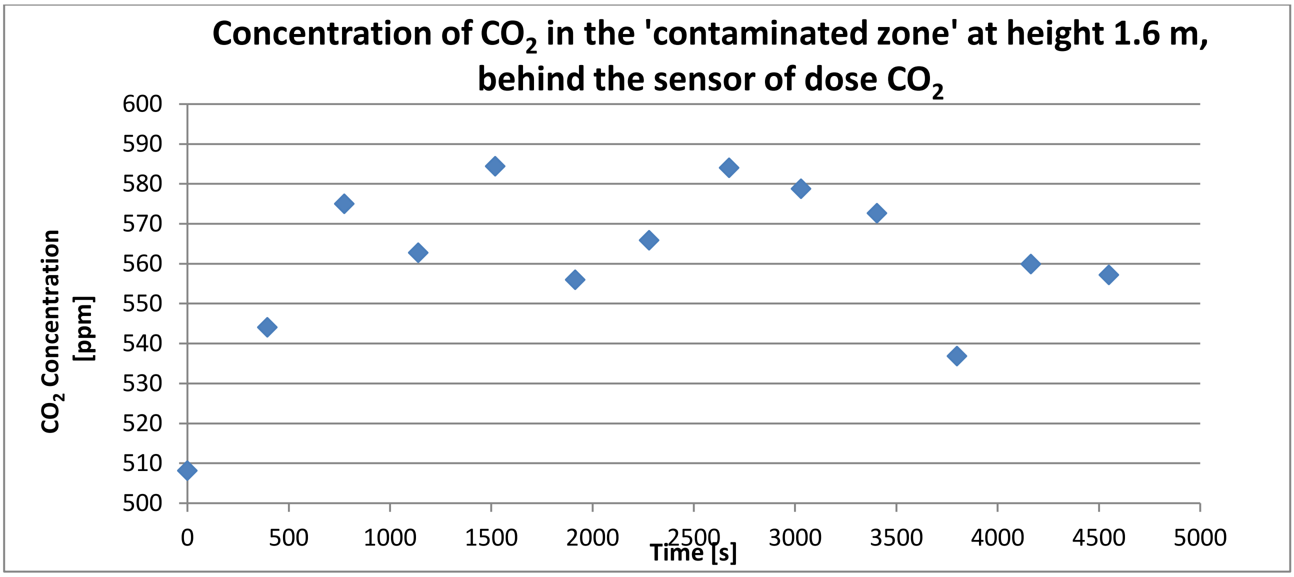
8	07:35:27	2665	475.37
9	07:41:32	3030	470.69
10	07:47:47	3405	466.20
11	07:53:52	3770	474.35
12	08:00:27	4165	466.24
13	08:06:52	4550	473.22



Graph 22. Concentration of CO_2 in the 'protected zone' at height 1.1 m - series no. 2 case no. 2.1

Table 28. Tabular listing of CO_2 concentration in the 'protected zone' at height 1.1 m - series no. 2 case no. 2.1

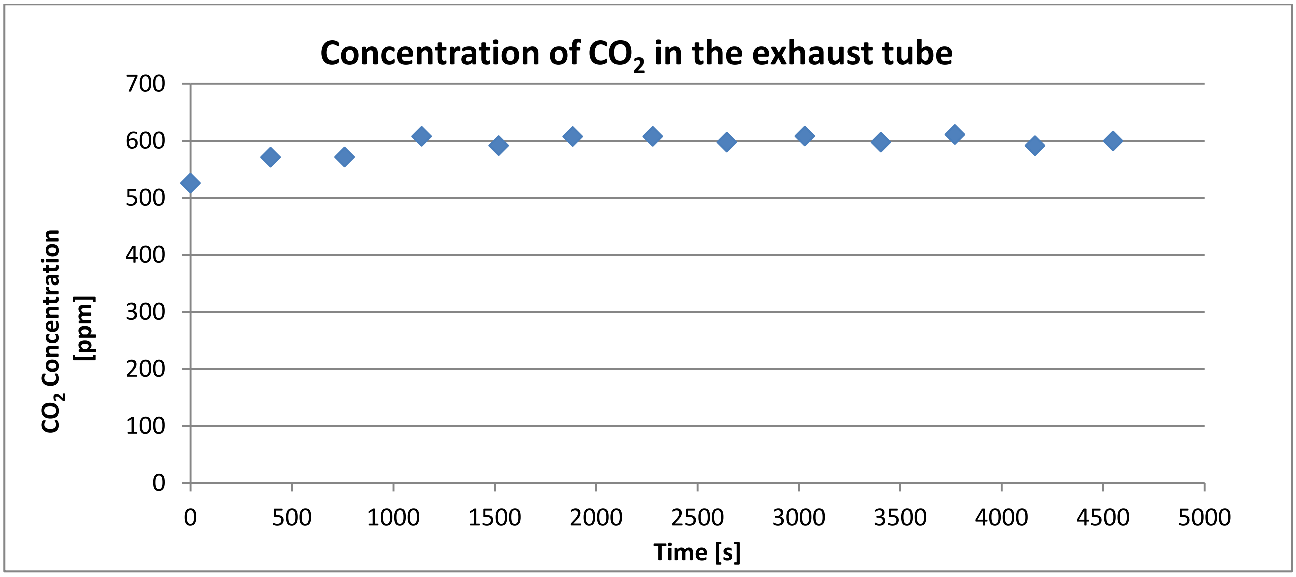
Concentration of CO_2 in the 'protected zone' at height 1.1 m			
No.	Time		CO2 concentration
	hh:mm:ss	s	ppm
1	06:59:37	0	462.28
2	07:05:57	380	479.84
3	07:12:02	745	492.35
4	07:18:22	1125	479.08
5	07:24:27	1490	480.22
6	07:31:02	1885	479.98
7	07:37:27	2270	785.01
8	07:43:32	2635	496.30
9	07:49:47	3010	480.07
10	07:56:22	3405	485.56
11	08:02:27	3770	491.55
12	08:08:52	4155	487.36



Graph 23. Concentration of CO_2 in the 'contaminated zone' at height 1.6 m, behind the sensor of dose CO_2 – series no. 2 case no. 2.1

Table 29. Tabular listing of CO_2 concentration in the 'contaminated zone' at height 1.6 m, behind the sensor of dose CO_2 – series no. 2 case no. 2.1

Contaminated zone -1.6m behind the sensor of dose CO2			
No.	Time		CO2 concentration
	hh:mm:ss	s	ppm
1	06:54:02	0	508.18
2	07:00:37	395	544.09
3	07:06:57	775	575.03
4	07:13:02	1140	562.78
5	07:19:22	1520	584.44
6	07:25:57	1915	556.00
7	07:32:02	2280	565.90
8	07:38:37	2675	584.05
9	07:44:32	3030	578.80
10	07:50:47	3405	572.68
11	07:57:22	3800	536.88
12	08:03:27	4165	559.94
13	08:09:52	4550	557.22

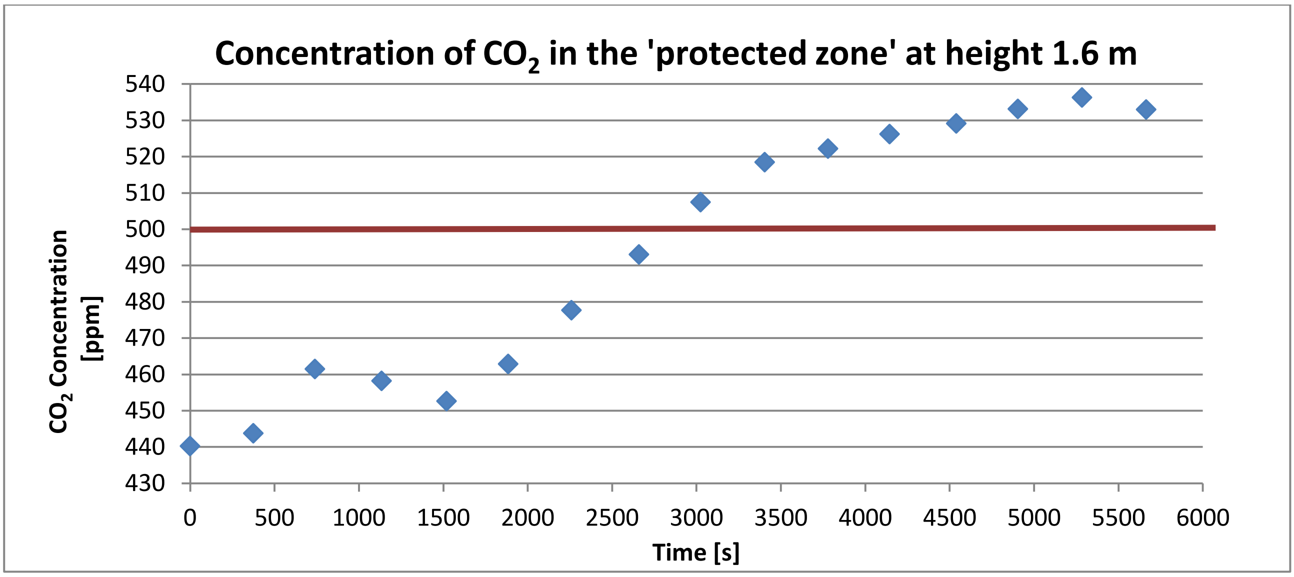


Graph 24. Concentration of CO_2 in the exhaust tube – series no. 2 case no. 2.1

Table 30. Tabular listing of CO_2 concentration in the exhaust tube – series no. 2 case no. 2.1

Concentration of CO_2 in the exhaust tube			
No.	Time		CO2 concentration
	hh:mm:ss	s	ppm
1	06:49:57	0	526.04
2	06:56:32	395	571.53
3	07:02:37	760	571.8
4	07:08:57	1140	608.05
5	07:15:17	1520	591.81
6	07:21:22	1885	607.77
7	07:27:57	2280	607.99
8	07:34:02	2645	597.88
9	07:40:27	3030	608.49
10	07:46:42	3405	597.88
11	07:52:47	3770	611.27
12	07:59:22	4165	591.65
13	08:05:47	4550	599.96

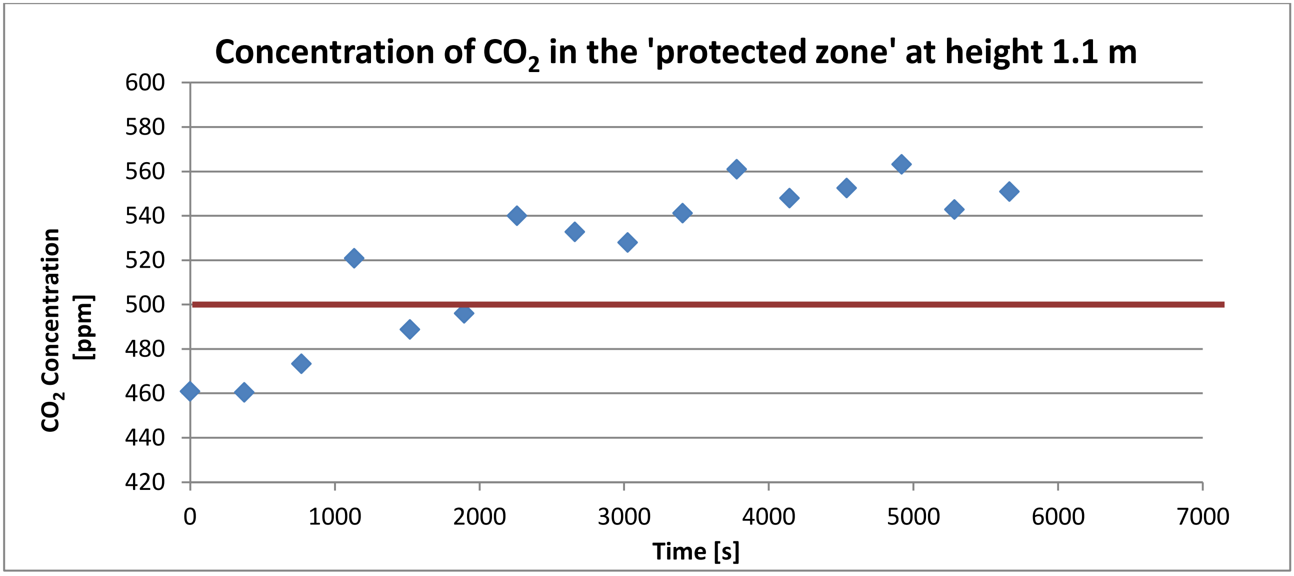
- **Case No. 2.2**



Graph 25. Concentration of CO_2 in the 'protected zone' at height 1.6 m –series no. 2 case 2.2

Table 31. Tabular listing of CO_2 concentration in the 'protected zone' at height 1.6 m –series no. 2 case 2.2

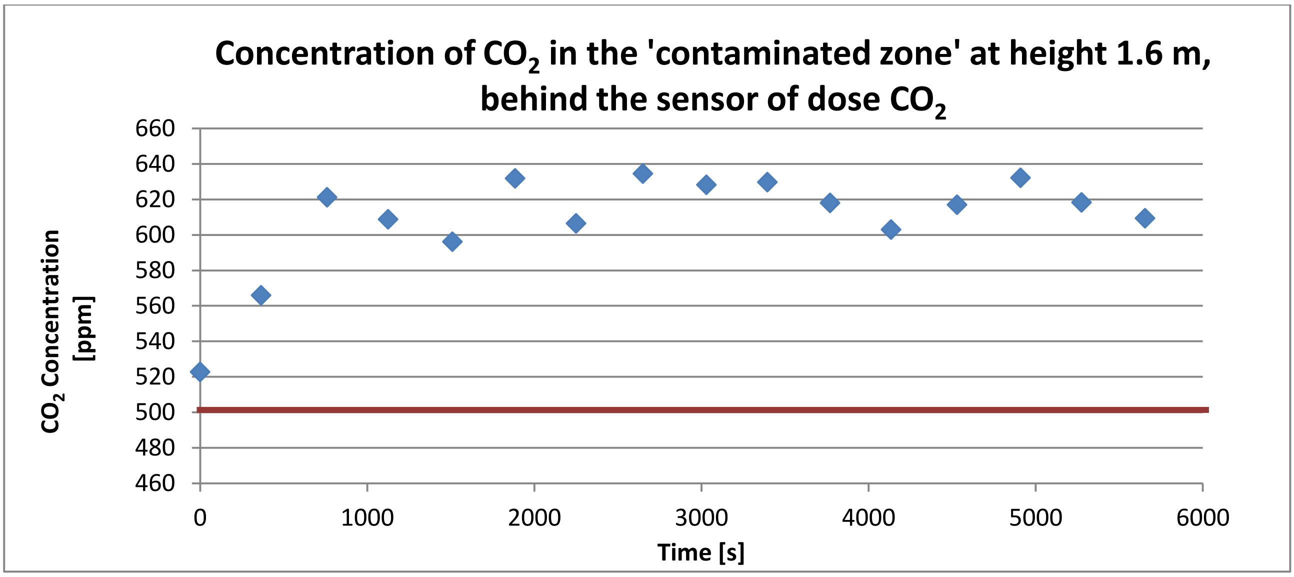
Concentration of CO_2 in the 'protected zone' at height 1.6 m			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	01:12:19	0	440.28
2	01:18:34	375	443.81
3	01:24:39	740	461.52
4	01:31:14	1135	458.25
5	01:37:39	1520	452.67
6	01:43:44	1885	462.91
7	01:49:59	2260	477.72
8	01:56:39	2660	493.09
9	02:02:44	3025	507.5
10	02:09:04	3405	518.52
11	02:15:19	3780	522.25
12	02:21:24	4145	526.26
13	02:27:59	4540	529.19
14	02:34:04	4905	533.19
15	02:40:24	5285	536.34
16	02:46:44	5665	533.03



Graph 26. Concentration of CO_2 in the 'protected zone' at height 1.1 m – series no. 2 case 2.2

Table 32. Tabular listing of CO_2 concentration in the 'protected zone' at height 1.1 m – series no. 2 case 2.2

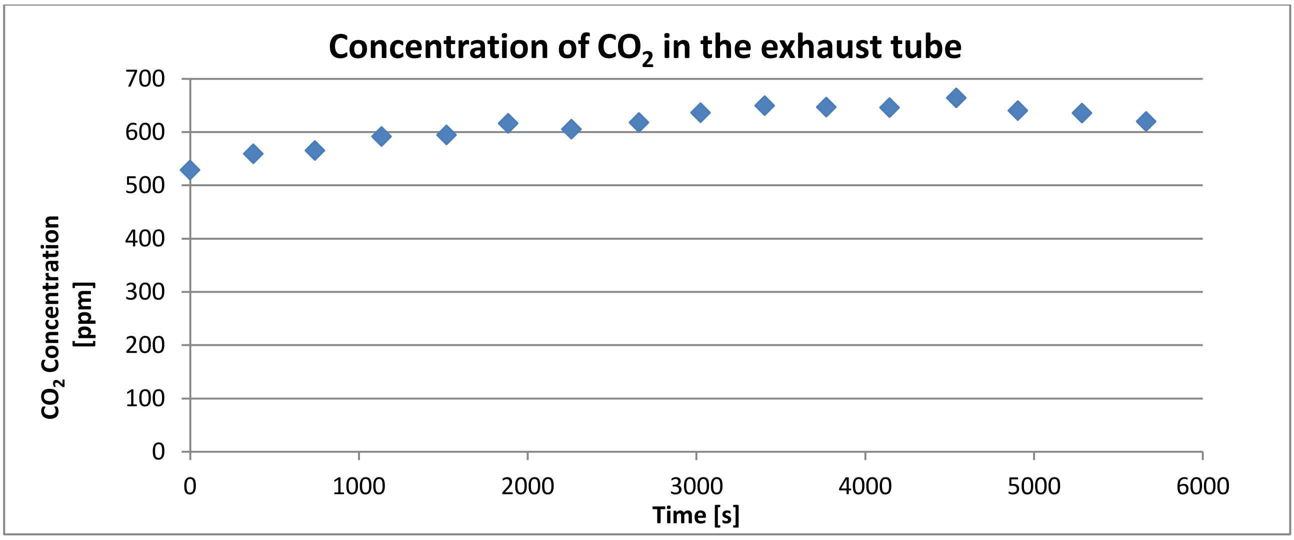
Concentration of CO_2 in the 'protected zone' at height 1.1 m			
No.	Time		CO2 concentration
	hh:mm:ss	s	ppm
1	01:14:19	0	460.96
2	01:20:34	375	460.51
3	01:27:09	770	473.39
4	01:33:14	1135	520.92
5	01:39:39	1520	488.84
6	01:45:54	1895	496.1
7	01:51:59	2260	540.08
8	01:58:39	2660	532.82
9	02:04:44	3025	528.03
10	02:11:04	3405	541.25
11	02:17:19	3779	561.03
12	02:23:24	4144	548.02
13	02:29:59	4539	552.56
14	02:36:19	4919	563.25
15	02:42:24	5284	542.9
16	02:48:44	5664	550.97



Graph 27. Concentration of CO_2 in the 'contaminated zone' at height 1.6 m, behind the sensor of dose CO_2 – series no.2 case no. 2.2

Table 33. Tabular listing of CO_2 concentration in the 'contaminated zone' at height 1.6 m, behind the sensor of dose CO_2 – series no.2 case no. 2.2

Contaminated zone -1.6m behind the sensor of dose CO_2			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	01:15:29	0	522.82
2	01:21:34	365	566.01
3	01:28:09	760	621.28
4	01:34:14	1125	608.87
5	01:40:39	1510	596.24
6	01:46:54	1885	631.94
7	01:52:59	2250	606.57
8	01:59:39	2650	634.62
9	02:05:59	3030	628.33
10	02:12:04	3395	629.81
11	02:18:19	3770	618.11
12	02:24:24	4135	603.07
13	02:30:59	4530	617.07
14	02:37:19	4910	632.27
15	02:43:24	5275	618.38
16	02:49:44	5655	609.47



Graph 28. Concentration of CO_2 in the exhaust tube – series no. 2 case 2.2

Table 34. Tabular listing of CO_2 concentration in the exhaust tube – series no. 2 case 2.2

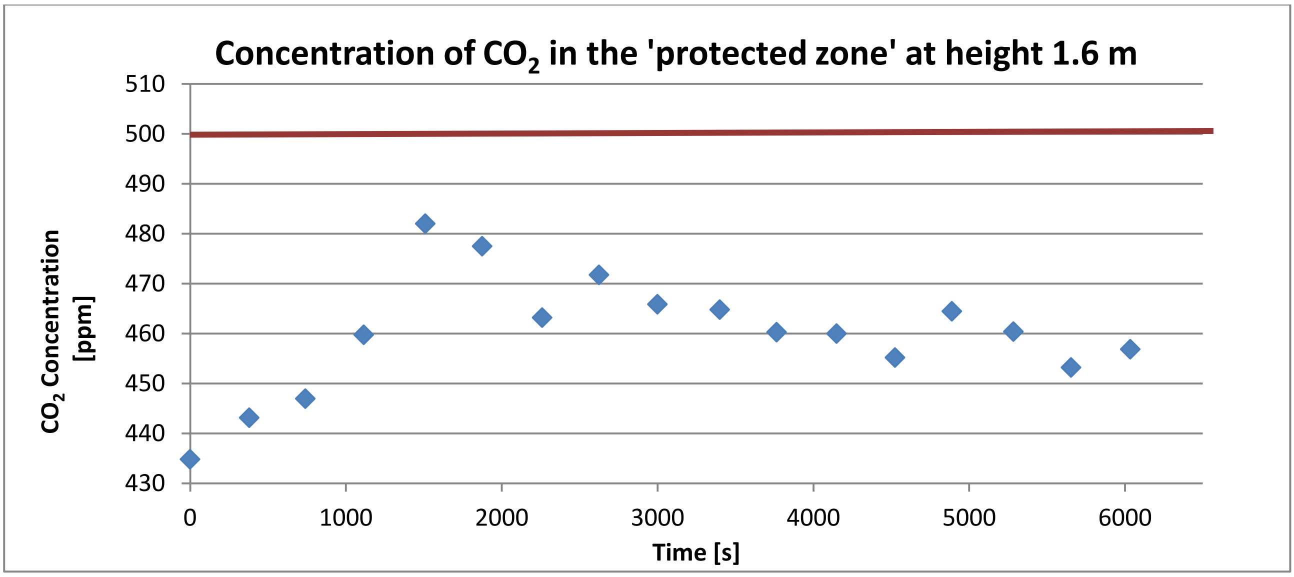
Concentration of CO_2 in the exhaust tube			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	01:11:14	0	529.09
2	01:17:29	375	559.55
3	01:23:34	740	565.62
4	01:30:09	1135	591.92
5	01:36:34	1520	594.87
6	01:42:39	1885	616.63
7	01:48:54	2260	605.64
8	01:55:34	2660	618.22
9	02:01:39	3025	636.59
10	02:07:59	3405	649.82
11	02:14:04	3770	647.14
12	02:20:19	4145	646.15
13	02:26:54	4540	664.41
14	02:32:59	4905	640.52
15	02:39:19	5285	635.93
16	02:45:39	5665	620.18

Series no. 2 include just two cases. Case no. 2.1 presented conditions which able to separate two zones. The average results shows that downward plane jet does not operate on the border limits. The mean values of CO_2 concentration at height 1.1 is rather high, namely is kept at level 480 ppm, however the contamination at 1.6 m in protected zone is maintained in the appropriate range, on average 465 ppm. In contrast, in the case no. 2.2 the volume of supply and exhaust air is not enough to fulfill the objective pursued. In every measurement points in protected zone, the upper limit of CO_2 concentration was exceeded many times. As in series no 1. respective and minimal value of exhaust air which able to protect select zone is equal to 400 m^3/h. Nonetheless case no. 2.1 is recommended because less amount of supply air and related to a reducing internal velocity of jet makes that proposed ventilation solutions is more energy-efficient. Moreover, decrease of velocity in the downward jet influences to indoor air quality and thermal comfort surrounding people.

Table 35. Experimental series No. 3

Experimental series No. 3 - Measurement conditions				
Number of case	Jet supply velocity (m/s)	Volume of supply air [m^3/h]	Volume of exhaust air [m^3/h]	Dimensions of outlet opening [m]
3.1	3.67	117	435	0.04x1.00
3.2	3.67	117	400	0.04x1.00
3.3	3.67	117	375	0.04x1.00

- **Case No.3.1**

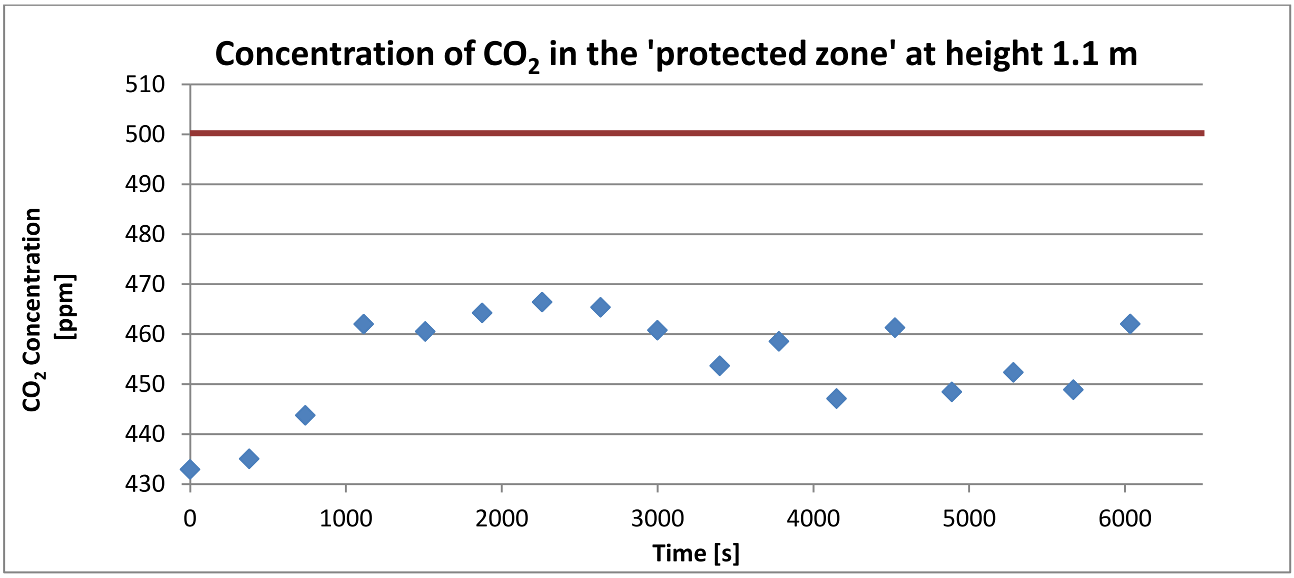


Graph 29. Concentration of CO_2 in the 'protected zone' at height 1.6 m – series no.3 case 3.1

Table 36. Tabular listing of CO_2 concentration in the 'protected zone' at height 1.6 m – series no.3 case 3.1

Concentration of CO_2 in the 'protected zone' at height 1.6 m			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	02:53:47	0	434.81
2	03:00:07	380	443.14
3	03:06:07	740	446.96
4	03:12:22	1115	459.76
5	03:18:57	1510	482.03

6	03:25:02	1875	477.51
7	03:31:27	2260	463.20
8	03:37:32	2625	471.77
9	03:43:47	3000	465.88
10	03:50:27	3400	464.80
11	03:56:32	3765	460.28
12	04:02:57	4150	460.00
13	04:09:12	4525	455.20
14	04:15:17	4890	464.47
15	04:21:52	5285	460.40
16	04:28:02	5655	453.21
17	04:34:22	6035	456.86

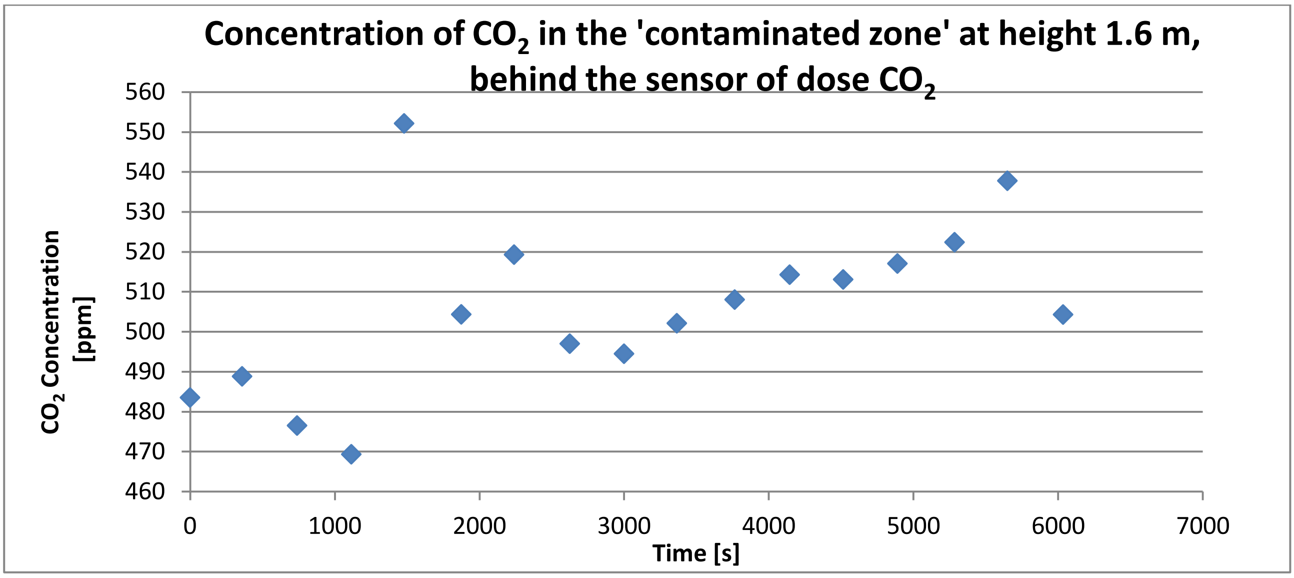


Graph 30. Concentration of CO_2 in the 'protected zone' at height 1.1 m – series no. 3 case no. 3.1

Table 37. Tabular listing of CO_2 concentration in the 'protected zone' at height 1.1 m – series no. 3 case no. 3.1

Concentration of CO_2 in the 'protected zone' at height 1.1 m			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	02:55:47	0	432.92
2	03:02:07	380	435.04
3	03:08:07	740	443.75
4	03:14:22	1115	462.02
5	03:20:57	1510	460.54
6	03:27:02	1875	464.26
7	03:33:27	2260	466.43
8	03:39:42	2635	465.38

9	03:45:47	3000	460.79
10	03:52:27	3400	453.67
11	03:58:47	3780	458.56
12	04:04:57	4150	447.10
13	04:11:12	4525	461.30
14	04:17:17	4890	448.44
15	04:23:52	5285	452.35
16	04:30:17	5670	448.88
17	04:36:22	6035	462.05

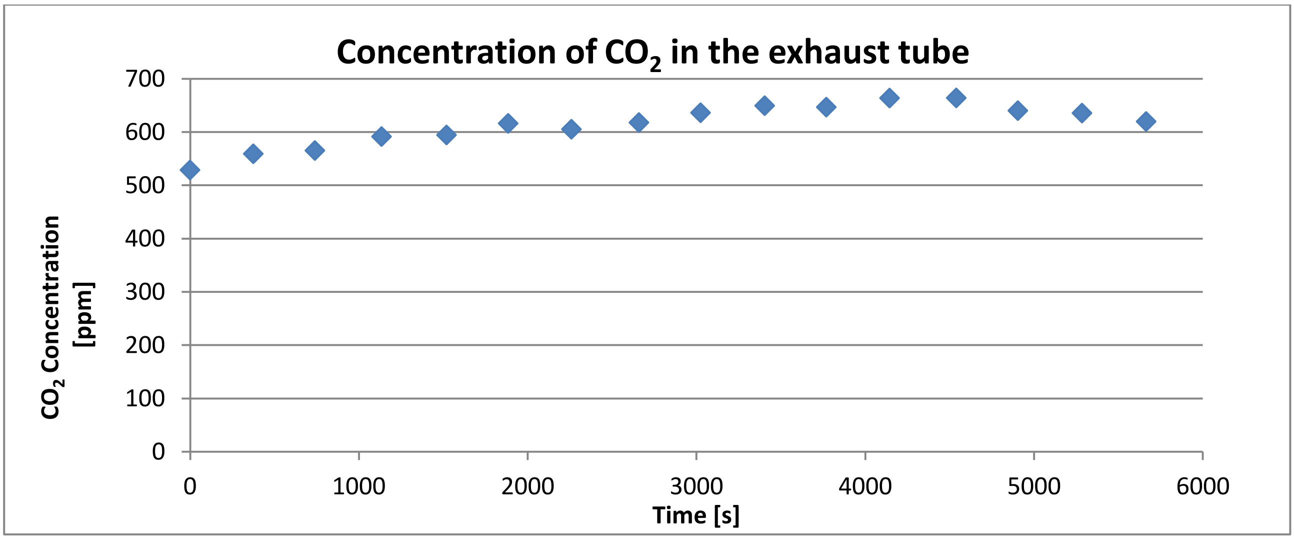


Graph 31. Concentration of CO_2 in the 'contaminated zone' at height 1.6 m, behind the sensor of dose CO_2 – series no. 3 case no. 3.1

Table 38. Tabular listing of CO_2 concentration in the 'contaminated zone' at height 1.6 m, behind the sensor of dose CO_2 – series no. 3 case no. 3.1

Contaminated zone -1.6m behind the sensor of dose CO_2			
No.	Time		CO_2 Concentration
	hh:mm:ss	s	ppm
1	02:50:42	0	483.51
2	02:56:42	360	488.81
3	03:03:02	740	476.50
4	03:09:17	1115	469.31
5	03:15:22	1480	552.12
6	03:21:57	1875	504.33
7	03:28:02	2240	519.28
8	03:34:27	2625	496.99
9	03:40:42	3000	494.47

10	03:46:47	3365	502.10
11	03:53:27	3765	508.02
12	03:59:47	4145	514.26
13	04:05:57	4515	513.07
14	04:12:12	4890	517.05
15	04:18:47	5285	522.38
16	04:24:52	5650	537.77
17	04:31:17	6035	504.28



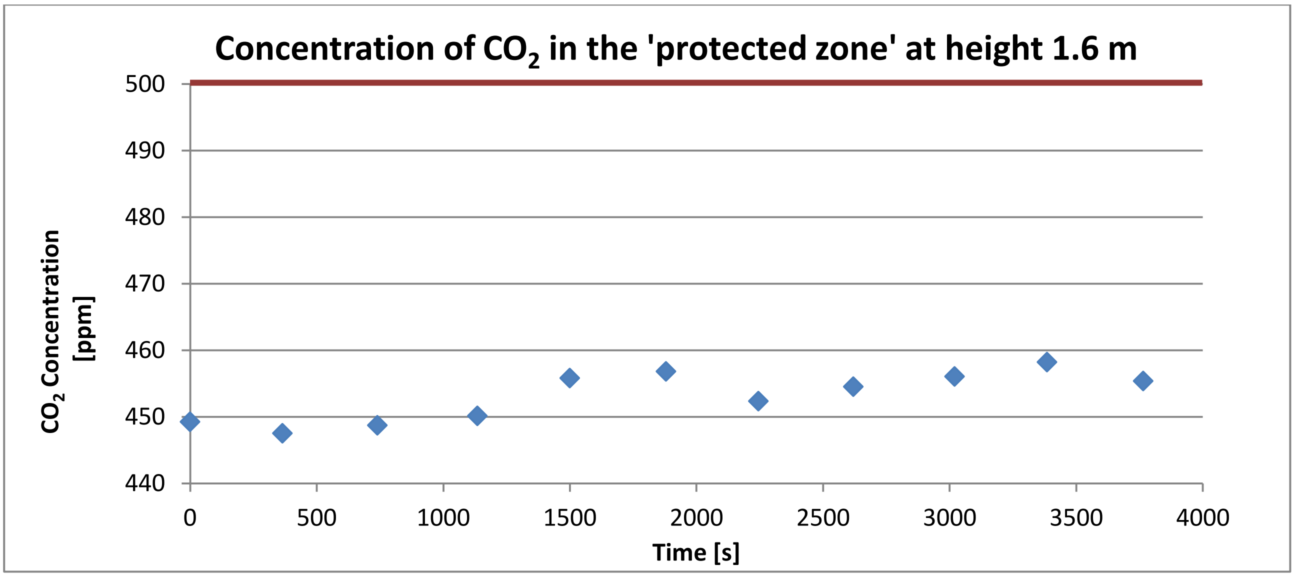
Graph 32. Concentration of CO_2 in the exhaust tube – series no. 3 case no. 3.1

Table 39. Tabular listing of CO_2 concentration in the exhaust tube – series no. 3 case no. 3.1

Concentration of CO_2 in the exhaust tube			
No.	Time		CO_2 Concentration
	hh:mm:ss	s	ppm
1	01:11:14	0	529.09
2	01:17:29	375	559.55
3	01:23:34	740	565.62
4	01:30:09	1135	591.92
5	01:36:34	1520	594.87
6	01:42:39	1885	616.63
7	01:48:54	2260	605.64
8	01:55:34	2660	618.22
9	02:01:39	3025	636.59
10	02:07:59	3405	649.82
11	02:14:04	3770	647.14
12	02:20:19	4145	664.15
13	02:26:54	4540	664.41
14	02:32:59	4905	640.52

15	02:39:19	5285	635.93
16	02:45:39	5665	620.18

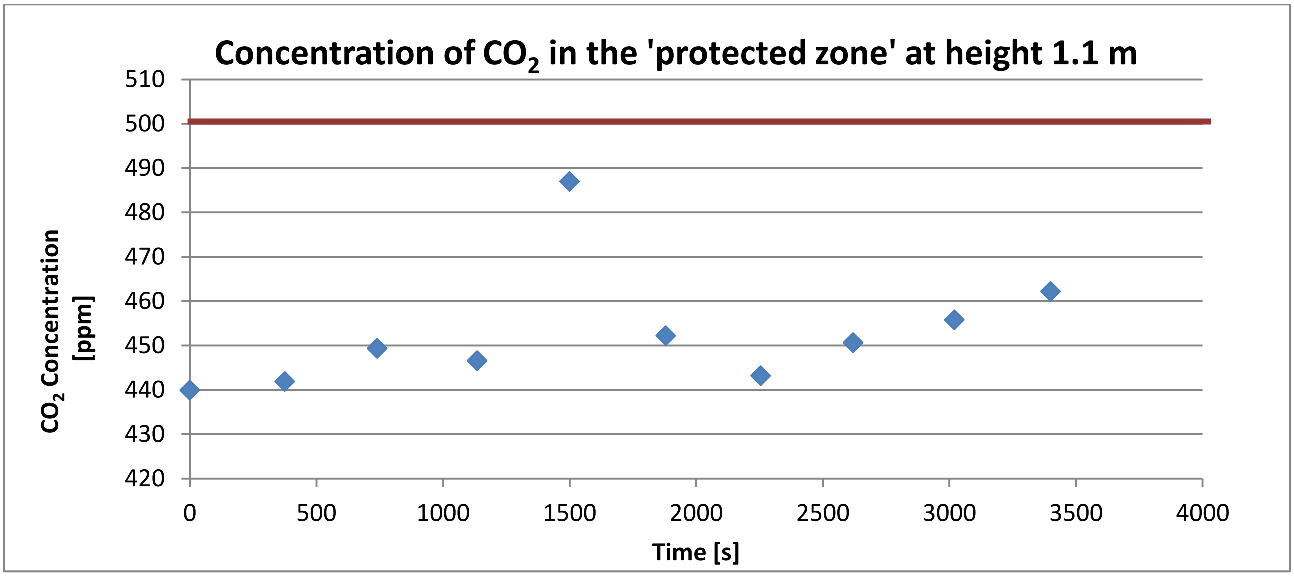
- **Case No. 3.2**



Graph 33. Concentration of CO_2 in the 'protected zone' at height 1.6 m – series no. 3 case no. 3.2

Table 40. Tabular listing of CO_2 concentration in the 'protected zone' at height 1.6 m – series no. 3 case no. 3.2

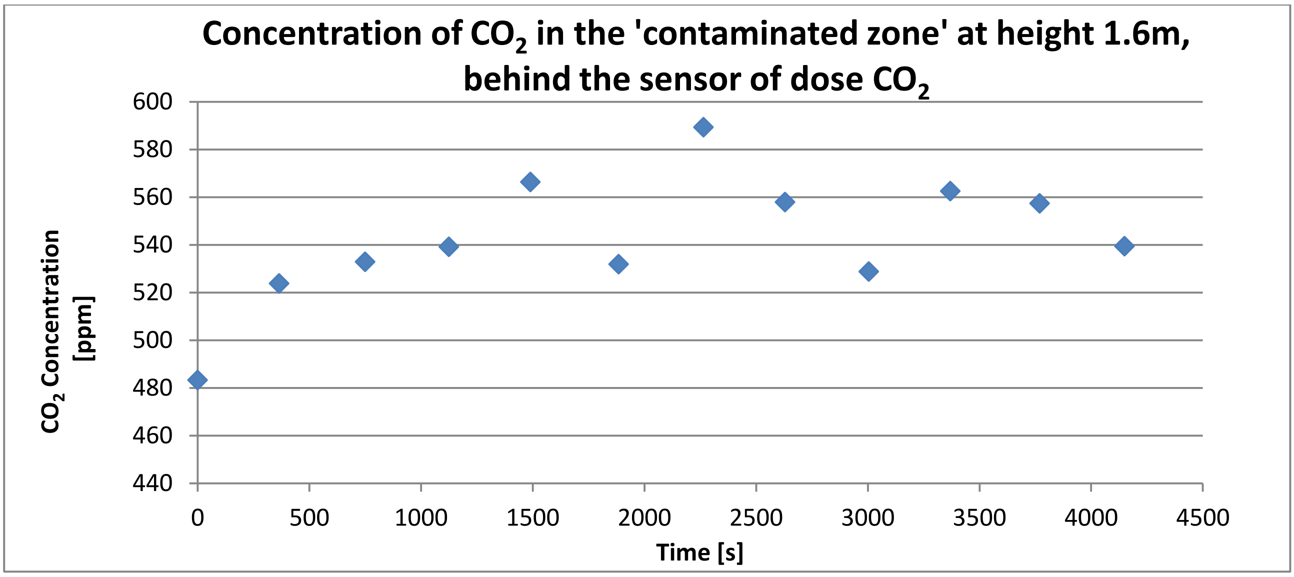
Concentration of CO_2 in the 'protected zone' at height 1.6 m			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	07:30:15	0	449.26
2	07:36:20	365	447.53
3	07:42:35	740	448.73
4	07:49:10	1135	450.15
5	07:55:15	1500	455.83
6	08:01:35	1880	456.83
7	08:07:40	2245	452.36
8	08:13:55	2620	454.54
9	08:20:35	3020	456.07
10	08:26:40	3385	458.23
11	08:33:00	3765	455.39



Graph 34. Concentration of CO_2 in the 'protected zone' at height 1.1 m – series no. 3 case no. 3.2

Table 41. Tabular listing of CO_2 concentration in the 'protected zone' at height 1.1 m – series no. 3 case no. 3.2

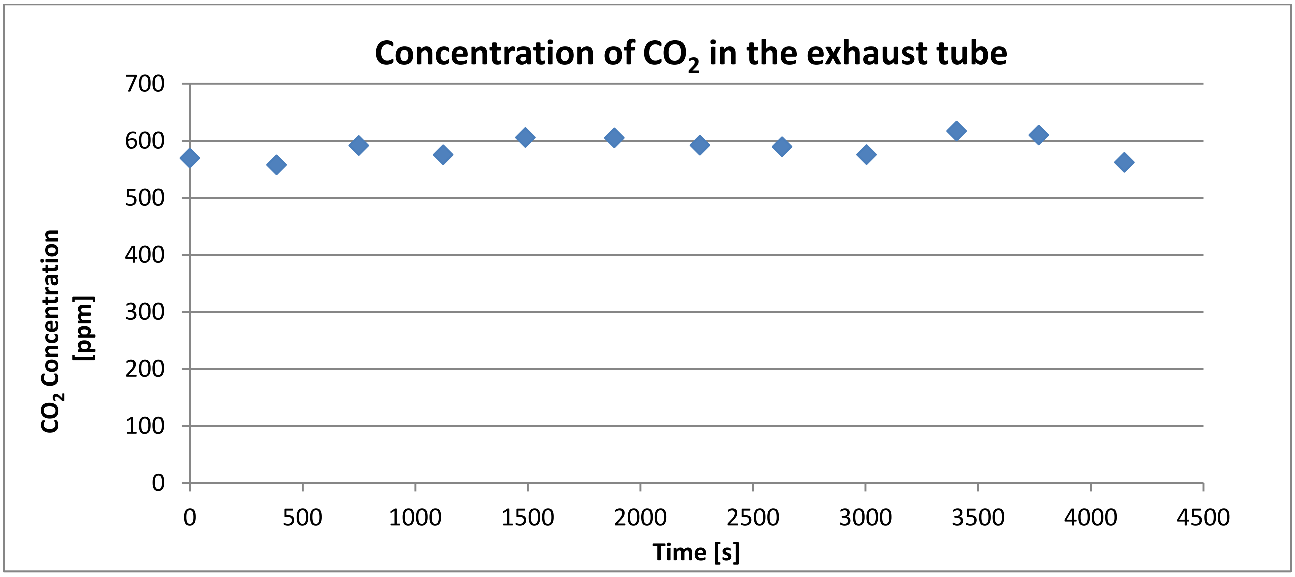
Concentration of CO_2 in the 'protected zone' at height 1.1 m			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	07:32:15	0	439.95
2	07:38:30	375	441.91
3	07:44:35	740	449.36
4	07:51:10	1135	446.60
5	07:57:15	1500	487.00
6	08:03:35	1880	452.23
7	08:09:50	2255	443.21
8	08:15:55	2620	450.67
9	08:22:35	3020	455.80
10	08:28:55	3400	462.22



Graph 35. Concentration of CO_2 in the 'contaminated zone' at height 1.6m, behind the sensor of dose CO_2 – series no. 3 case no. 3.2

Table 42. Tabular listing of CO_2 concentration in the 'contaminated zone' at height 1.6m, behind the sensor of dose CO_2 – series no. 3 case no. 3.2

Contaminated zone -1.6m behind the sensor of dose CO_2			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	07:20:45	0	483.31
2	07:26:50	365	523.84
3	07:33:15	750	532.92
4	07:39:30	1125	539.21
5	07:45:35	1490	566.39
6	07:52:10	1885	531.91
7	07:58:30	2265	589.37
8	08:04:35	2630	557.97
9	08:10:50	3005	528.82
10	08:16:55	3370	562.56
11	08:23:35	3770	557.42
12	08:29:55	4150	539.46

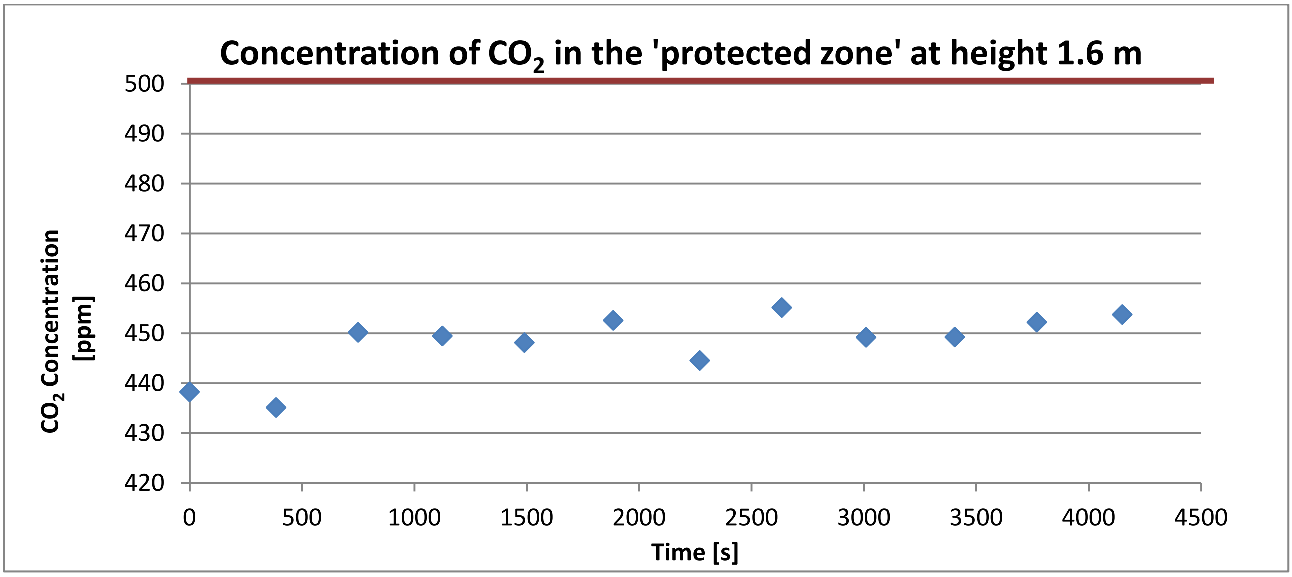


Graph 36. Concentration of CO_2 in the exhaust tube – series no. 3 case no 3.2

Table 43. Tabular listing of CO_2 concentration in the exhaust tube – series no. 3 case no 3.2

Concentration of CO_2 in the exhaust tube			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	07:22:45	0	569.95
2	07:29:10	385	558.02
3	07:35:15	750	591.97
4	07:41:30	1125	575.74
5	07:47:35	1490	606.02
6	07:54:10	1885	605.37
7	08:00:30	2265	592.52
8	08:06:35	2630	589.79
9	08:12:50	3005	576.01
10	08:19:30	3405	617.34
11	08:25:35	3770	610.29
12	08:31:55	4150	562.45

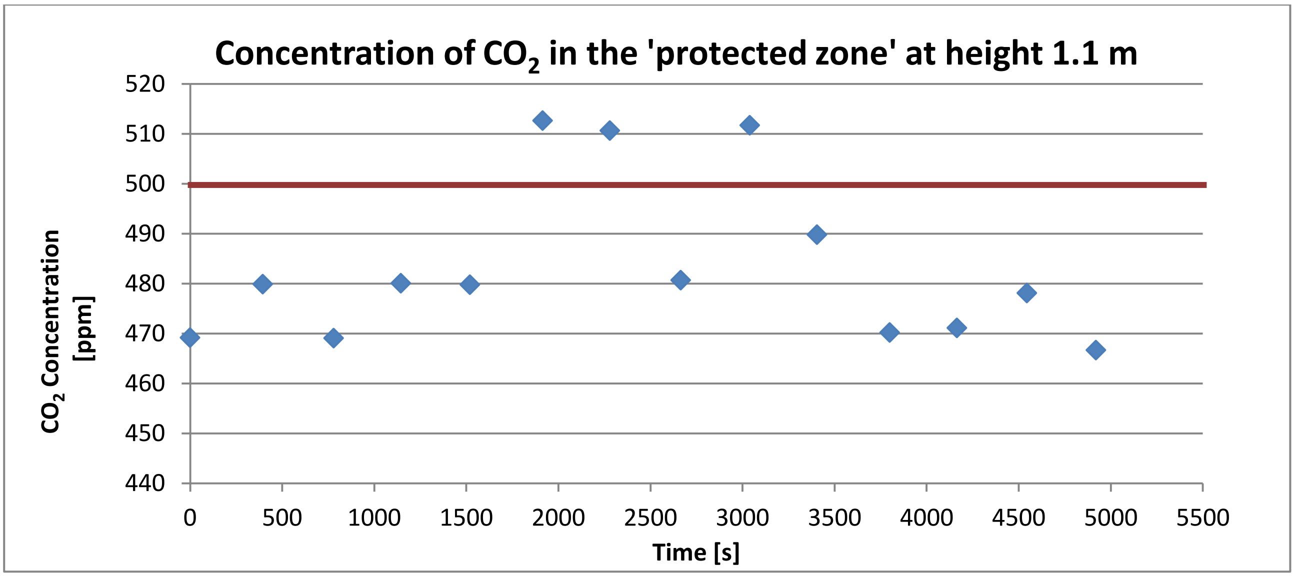
- **Case No. 3.3**



Graph 37. Concentration of CO_2 in the 'protected zone' at height 1.6 m – series no. 3 case no. 3.3

Table 44. Tabular listing of CO_2 concentration in the 'protected zone' at height 1.6 m – series no. 3 case no. 3.3

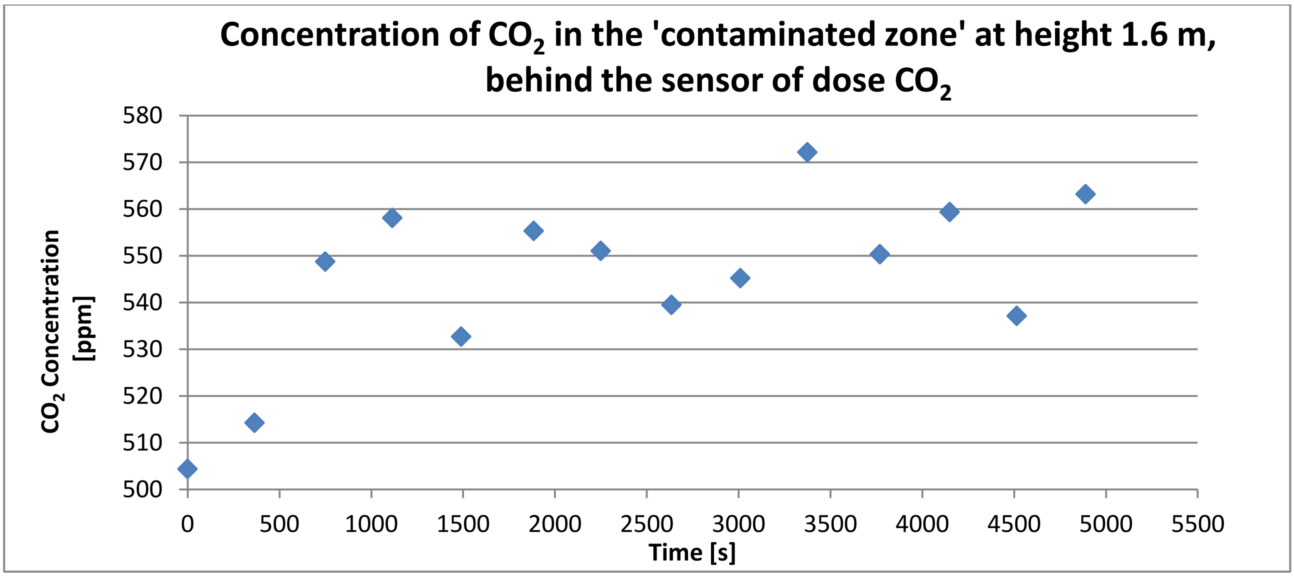
Concentration of CO_2 in the 'protected zone' at height 1.6 m			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	07:09:32	0	438.28
2	07:15:57	385	435.15
3	07:22:02	750	450.21
4	07:28:17	1125	449.49
5	07:34:22	1490	448.16
6	07:40:57	1885	452.61
7	07:47:22	2270	444.57
8	07:53:27	2635	455.18
9	07:59:42	3010	449.22
10	08:06:17	3405	449.28
11	08:12:22	3770	452.25
12	08:18:42	4150	453.78
13	08:24:47	4515	450.95



Graph 38. Concentration of CO_2 in the 'protected zone' at height 1.1 m – series no. 3 case no. 3.3

Table 45. Tabular listing of CO_2 concentration in the 'protected zone' at height 1.1 m – series no. 3 case no. 3.3

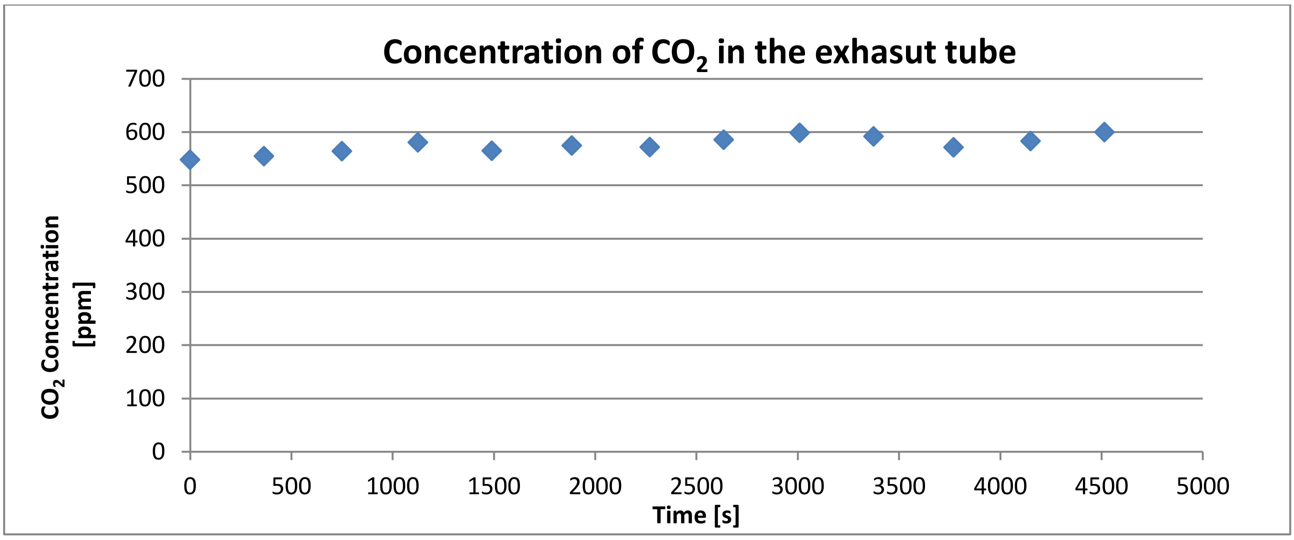
Concentration of CO_2 in the 'protected zone' at height 1.1 m			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	07:04:57	0	469.20
2	07:11:32	395	479.92
3	07:17:57	780	469.10
4	07:24:02	1145	480.11
5	07:30:17	1520	479.81
6	07:36:52	1915	512.70
7	07:42:57	2280	510.70
8	07:49:22	2665	480.72
9	07:55:37	3040	511.76
10	08:01:42	3405	489.84
11	08:08:17	3800	470.23
12	08:14:22	4165	471.15
13	08:20:42	4545	478.14
14	08:26:57	4920	466.70



Graph 39. Concentration of CO_2 in the 'contaminated zone' at height 1.6 m, behind the sensor of dose CO_2 – series no. 3 case no. 3.3

Table 46. Tabular listing of CO_2 concentration in the 'contaminated zone' at height 1.6 m, behind the sensor of dose CO_2 – series no. 3 case no. 3.3

Contaminated zone -1.6m behind the sensor of dose CO_2			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	07:06:27	0	504.42
2	07:12:32	365	514.30
3	07:18:57	750	548.78
4	07:25:02	1115	558.13
5	07:31:17	1490	532.74
6	07:37:52	1885	555.35
7	07:43:57	2250	551.08
8	07:50:22	2635	539.53
9	07:56:37	3010	545.25
10	08:02:42	3375	572.18
11	08:09:17	3770	550.37
12	08:15:37	4150	559.39
13	08:21:42	4515	537.17
14	08:27:57	4890	563.22



Graph 40. Concentration of CO_2 in the exhaust tube - series no. 3 case no. 3.3

Table 47. Tabular listing of CO_2 concentration in the exhaust tube - series no. 3 case no. 3.3

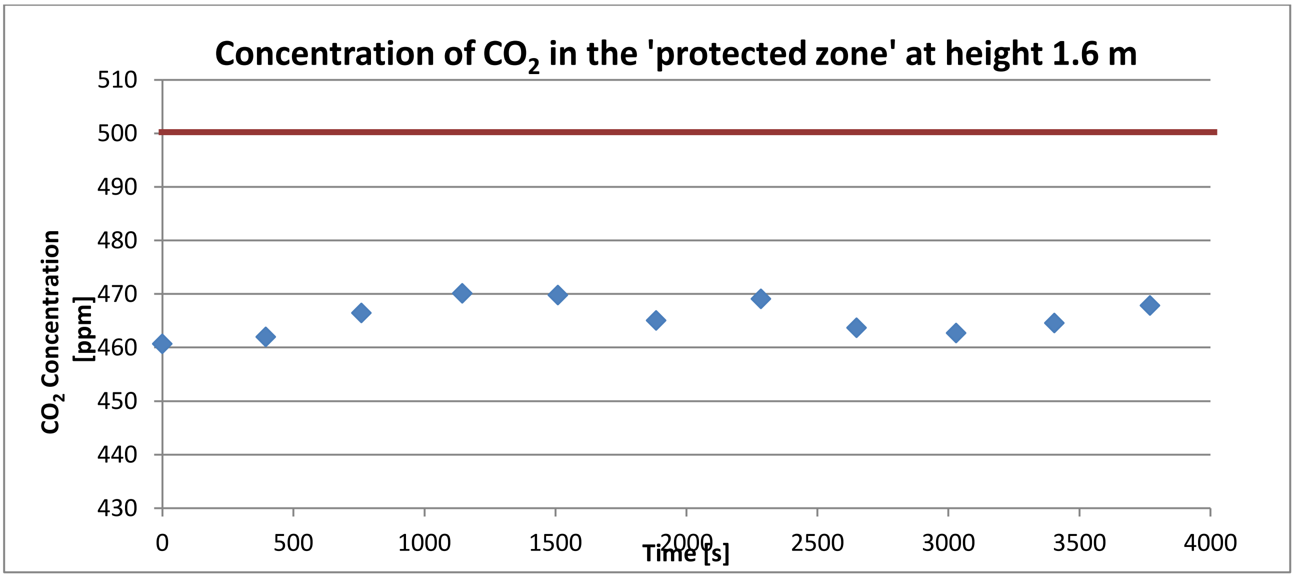
Concentration of CO_2 in the exhaust tube			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	07:08:27	0	548.35
2	07:14:32	365	555.07
3	07:20:57	750	564.42
4	07:27:12	1125	580.88
5	07:33:17	1490	565.13
6	07:39:52	1885	575.03
7	07:46:17	2270	572.07
8	07:52:22	2635	585.85
9	07:58:37	3010	598.81
10	08:04:42	3375	592.14
11	08:11:17	3770	571.64
12	08:17:37	4150	583.39
13	08:23:42	4515	600.18

Similarly as in series no. 1, in series no. 3 between results of case no. 3.1 (q_{exh}=435 m^3/h) and 3.2 (q_{exh}=400 m^3/h) is almost no difference. Moreover, again limit of 500ppm in protected zone has been exceeded while reducing the amount of exhaust air to 375 m^3/h. Although the internal velocity was reduced by about 1.5 m/s, the CO_2 concentration in protected zone maintains at low level. At height 1.6 m the concentration is kept about 453 ppm and at height 1.1 m is on average at 450 ppm. While indicating the proper case of series no.3 a decisive factor was a value of air parameters. Thus, the recommended case is case no. 3.2.

Table 48. Experimental series No. 4

Experimental series No. 4 - Measurement conditions				
Number of case	Jet supply velocity (m/s)	Volume of supply air [m^3/h]	Volume of exhaust air [m^3/h]	Dimensions of outlet opening [m]
4.1	2.47	78	435	0.04x1.00
4.2	2.47	78	400	0.04x1.00
4.3	2.47	78	375	0.04x1.00
4.4	2.47	78	310	0.04x1.00
4.5	2.47	78	250	0.04x1.00
4.6	2.47	78	220	0.04x1.00

- **Case No. 4.1**

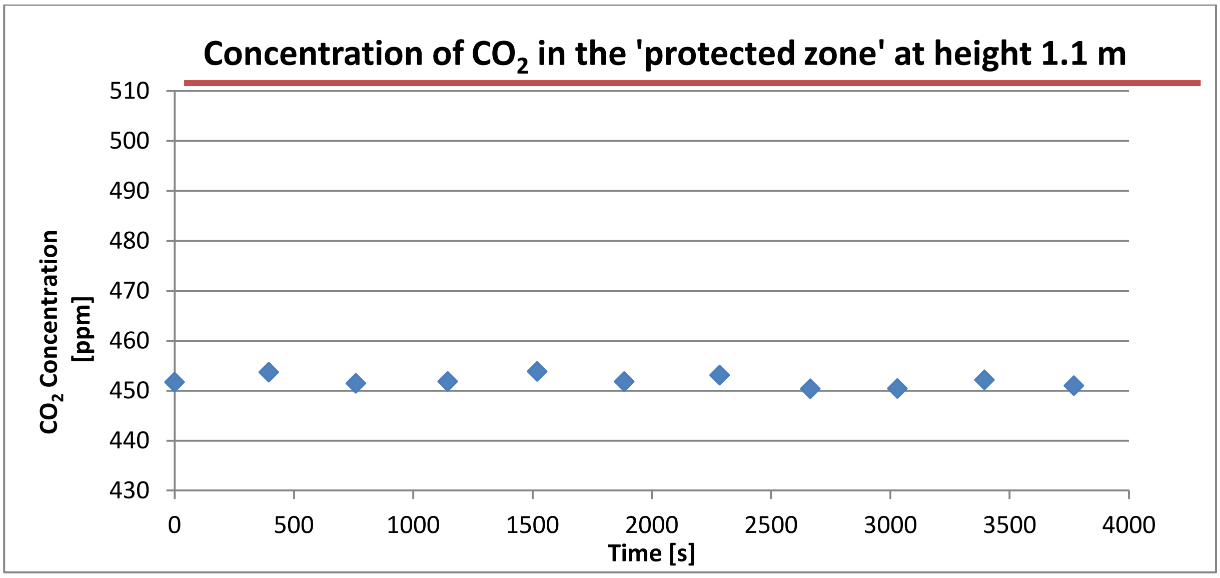


Graph 41. Concentration of CO_2 in the 'protected zone' at height 1.6 m – series no. 4 case no. 4.1

Table 49. Tabular listing of CO_2 concentration in the 'protected zone' at height 1.6 m – series no. 4 case no. 4.1

Concentration of CO_2 in the 'protected zone' at height 1.6 m			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	05:31:50	0	460.72
2	05:38:25	395	462.02
3	05:44:30	760	466.49
4	05:50:55	1145	470.15
5	05:57:00	1510	469.83
6	06:03:15	1885	465.09
7	06:09:55	2285	469.12
8	06:16:00	2650	463.72

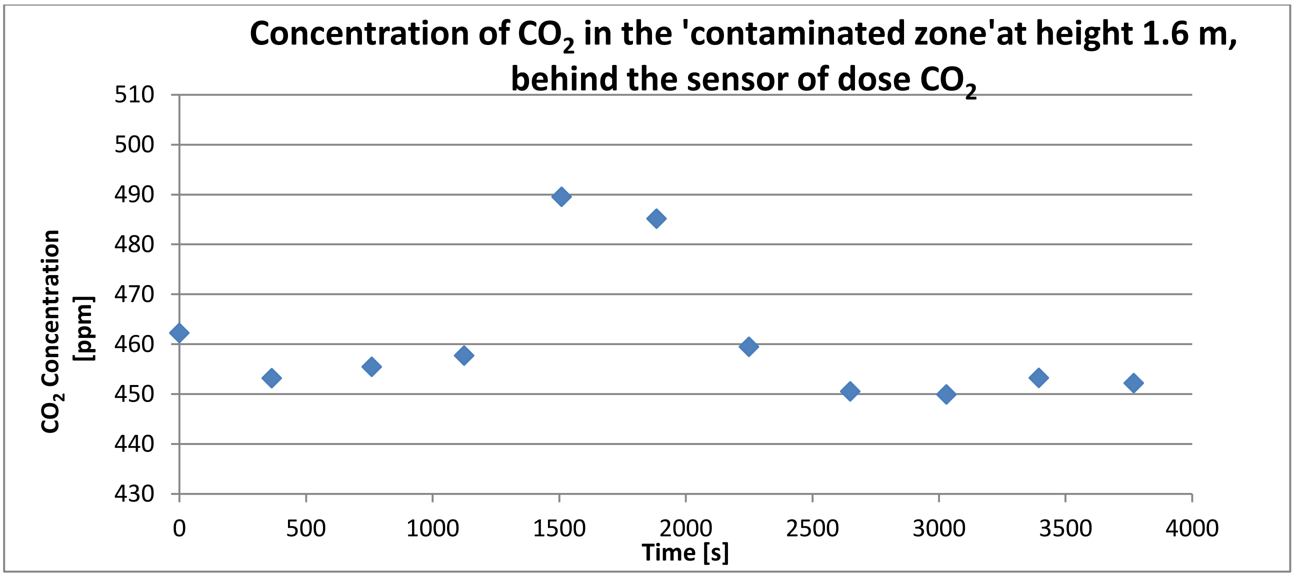
9	06:22:20	3030	462.74
10	06:28:35	3405	464.61
11	06:34:40	3770	467.88



Graph 42. Concentration of CO_2 in the 'protected zone' at height 1.1 m – series no. 4 case no. 4.1

Table 50. Tabular listing of CO_2 concentration in the 'protected zone' at height 1.1 m – series no. 4 case no. 4.1

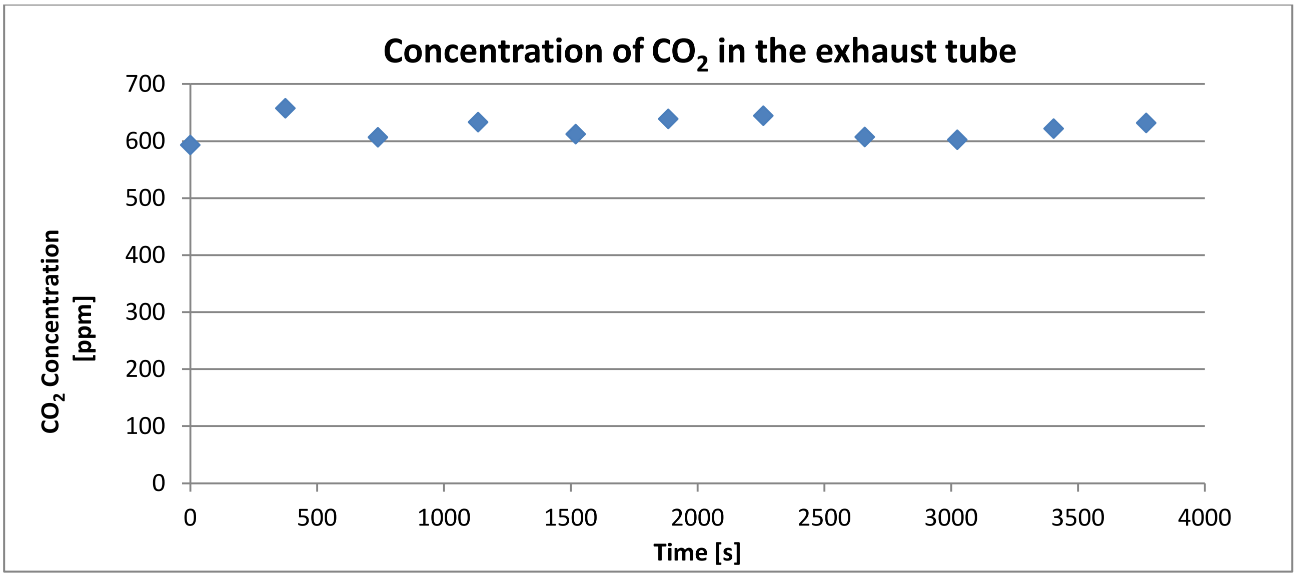
Concentration of CO_2 in the 'protected zone' at height 1.1 m			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	05:33:50	0	451.72
2	05:40:25	395	453.71
3	05:46:30	760	451.48
4	05:52:55	1145	451.85
5	05:59:10	1520	453.86
6	06:05:15	1885	451.83
7	06:11:55	2285	453.12
8	06:18:15	2665	450.38
9	06:24:20	3030	450.44
10	06:30:25	3395	452.17
11	06:36:40	3770	451.01



Graph 43. Concentration of CO_2 in the 'contaminated zone' at height 1.6 m, behind the sensor of dose CO_2 – series no. 4 case no. 4.1

Table 51. Tabular listing of CO_2 concentration in the 'contaminated zone' at height 1.6 m, behind the sensor of dose CO_2 – series no. 4 case no. 4.1

Contaminated zone -1.6m behind the sensor of dose CO_2			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	05:28:45	0	462.27
2	05:34:50	365	453.21
3	05:41:25	760	455.49
4	05:47:30	1125	457.74
5	05:53:55	1510	489.56
6	06:00:10	1885	485.18
7	06:06:15	2250	459.5
8	06:12:55	2650	450.56
9	06:19:15	3030	449.95
10	06:25:20	3395	453.27
11	06:31:35	3770	452.22

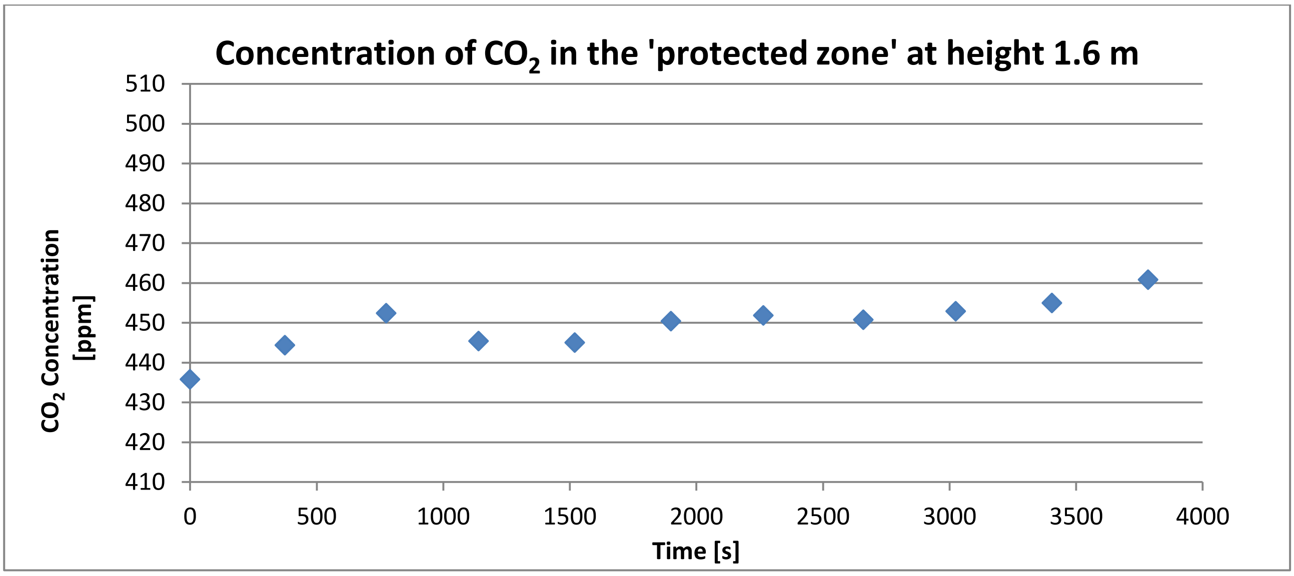


Graph 44. Concentration of CO_2 in the exhaust tube – series no. 4 case no. 4.1

Table 52. Tabular listing of CO_2 concentration in the exhaust tube – series no. 4 case no. 4.1

Concentration of CO_2 in the exhaust tube			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	05:24:30	0	593.29
2	05:30:45	375	657.69
3	05:36:50	740	606.84
4	05:43:25	1135	633.41
5	05:49:50	1520	612.37
6	05:55:55	1885	639.05
7	06:02:10	2260	644.62
8	06:08:50	2660	607.34
9	06:14:55	3025	602.47
10	06:21:15	3405	622.04
11	06:27:20	3770	632.01

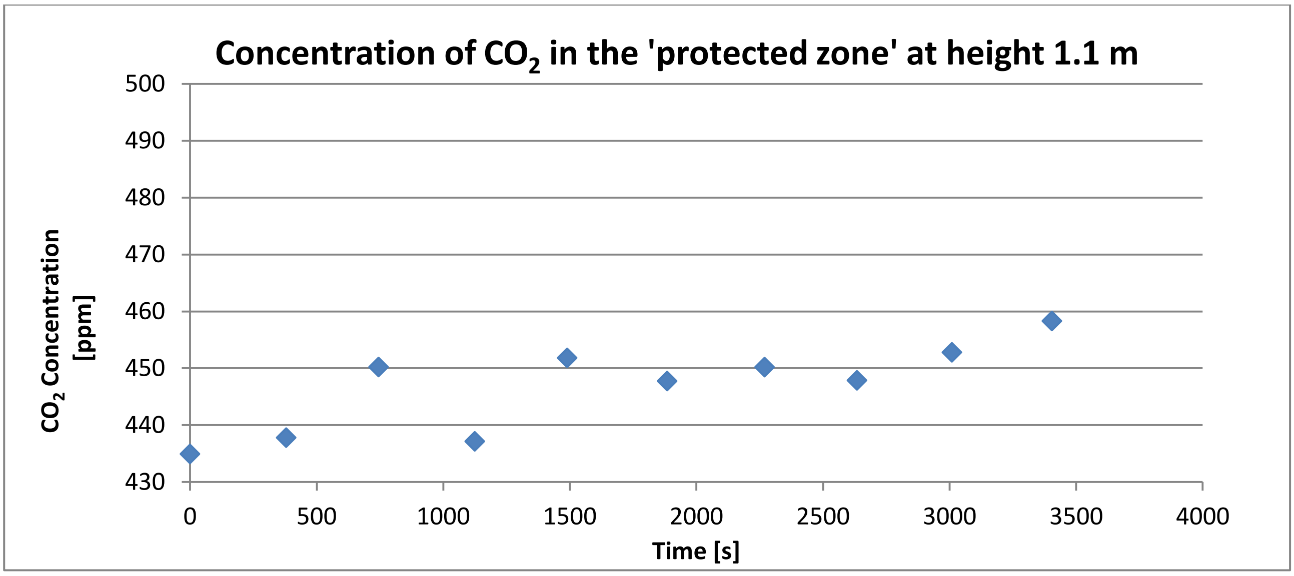
- **Case No. 4.2**



Graph 45. Concentration of CO_2 in the 'protected zone' at height 1.6 m – series no. 4 case no. 4.2

Table 53. Tabular listing of CO_2 concentration in the 'protected zone' at height 1.6 m – series no. 4 case no. 4.2

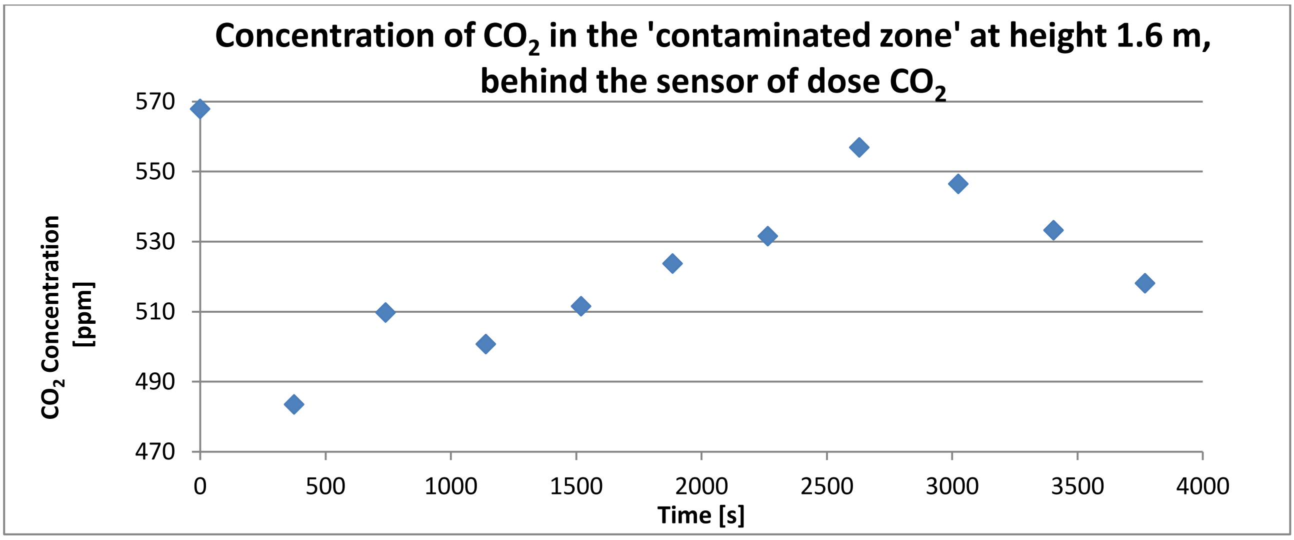
Concentration of CO_2 in the 'protected zone' at height 1.6 m			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	07:28:53	0	435.83
2	07:35:08	375	444.40
3	07:41:48	775	452.44
4	07:47:53	1140	445.44
5	07:54:13	1520	445.06
6	08:00:33	1900	450.44
7	08:06:38	2265	451.88
8	08:13:13	2660	450.79
9	08:19:18	3025	452.93
10	08:25:38	3405	455.00
11	08:31:58	3785	460.85



Graph 46. Concentration of CO_2 in the 'protected zone' at height 1.1 m – series no. 4 case no. 4.2

Table 54. Tabular listing of CO_2 concentration in the 'protected zone' at height 1.1 m – series no. 4 case no. 4.2

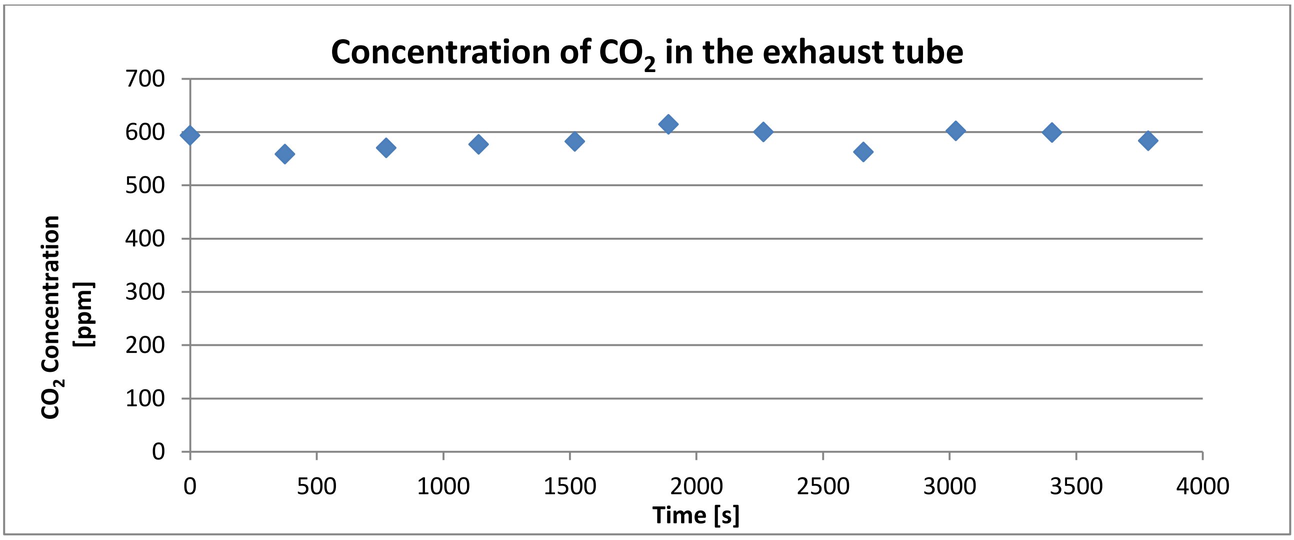
Concentration of CO_2 in the 'protected zone' at height 1.1 m			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	07:24:48	0	432.98
2	07:31:03	375	425.28
3	07:37:08	740	433.06
4	07:43:48	1140	434.11
5	07:49:53	1505	434.47
6	07:56:13	1885	450.22
7	08:02:33	2265	439.8
8	08:08:38	2630	447.1
9	08:15:13	3025	440.57
10	08:21:33	3405	445.46
11	08:27:38	3770	450.77



Graph 47. Concentration of CO_2 in the 'contaminated zone' at height 1.6 m, behind the sensor of dose CO_2 – series no. 4 case no. 4.2

Table 55. Tabular listing of CO_2 concentration in the 'contaminated zone' at height 1.6 m, behind the sensor of dose CO_2 – series no. 4 case no. 4.2

contaminated zone -1.6m behind the sensor of dose CO2			
No.	Time		CO2 concentration
	hh:mm:ss	s	ppm
1	07:25:48	0	567.92
2	07:32:03	375	483.54
3	07:38:08	740	509.78
4	07:44:48	1140	500.77
5	07:51:08	1520	511.58
6	07:57:13	1885	523.77
7	08:03:33	2265	531.59
8	08:09:38	2630	556.93
9	08:16:13	3025	546.52
10	08:22:33	3405	533.28
11	08:28:38	3770	518.14

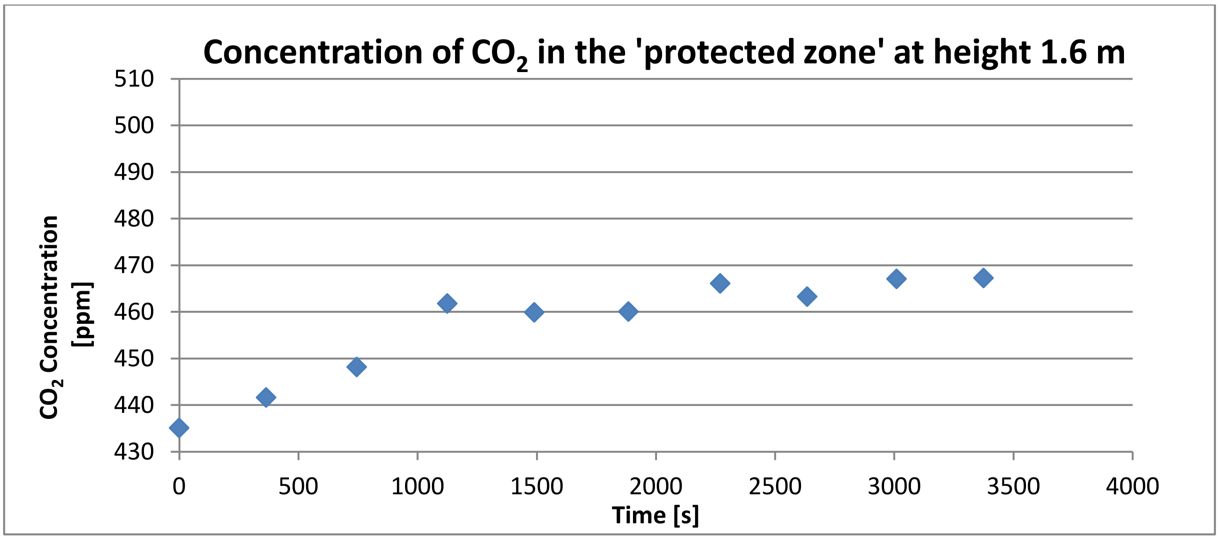


Graph 48. Concentration of CO_2 in the exhaust tube – series no. 4 case no. 4.2

Table 56. Tabular listing of CO_2 concentration in the exhaust tube – series no. 4 case no. 4.2

Concentration of CO_2 in the exhaust tube			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	07:27:48	0	594.05
2	07:34:03	375	558.88
3	07:40:43	775	570.60
4	07:46:48	1140	577.16
5	07:53:08	1520	582.68
6	07:59:18	1890	614.77
7	08:05:33	2265	600.50
8	08:12:08	2660	562.89
9	08:18:13	3025	602.53
10	08:24:33	3405	599.36
11	08:30:53	3785	583.99

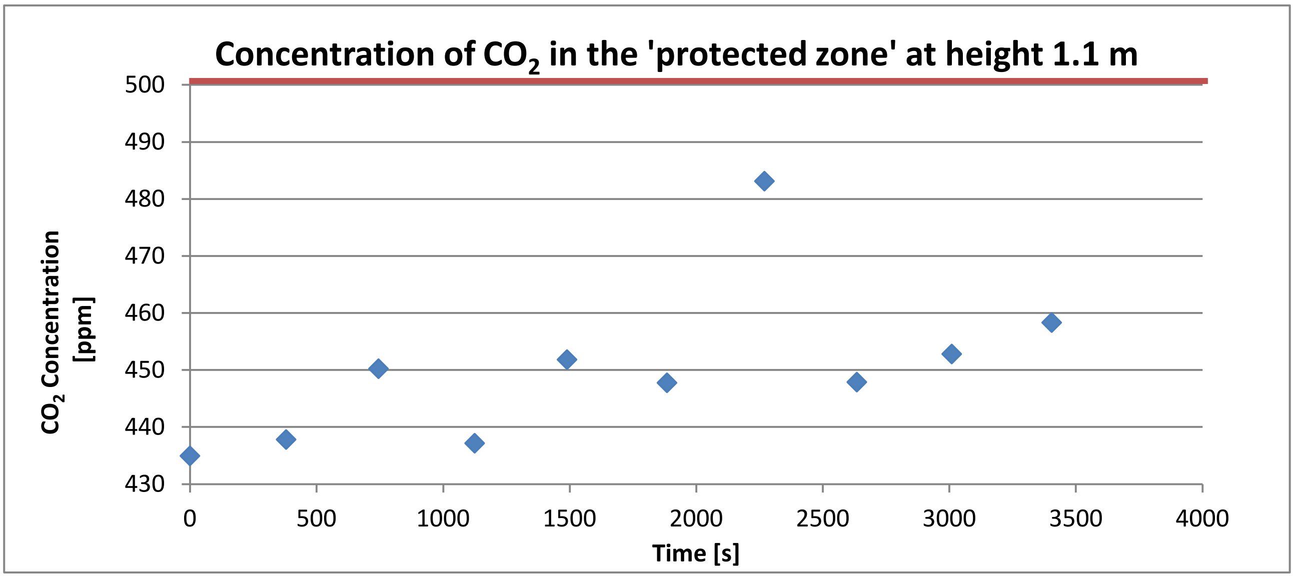
- **Case No. 4.3**



Graph 49. Concentration of CO_2 in the 'protected zone' at height 1.6 m – series no.4 case 4.3

Table 57. Tabular listing of CO_2 concentration in the 'protected zone' at height 1.6 m – series no.4 case 4.3

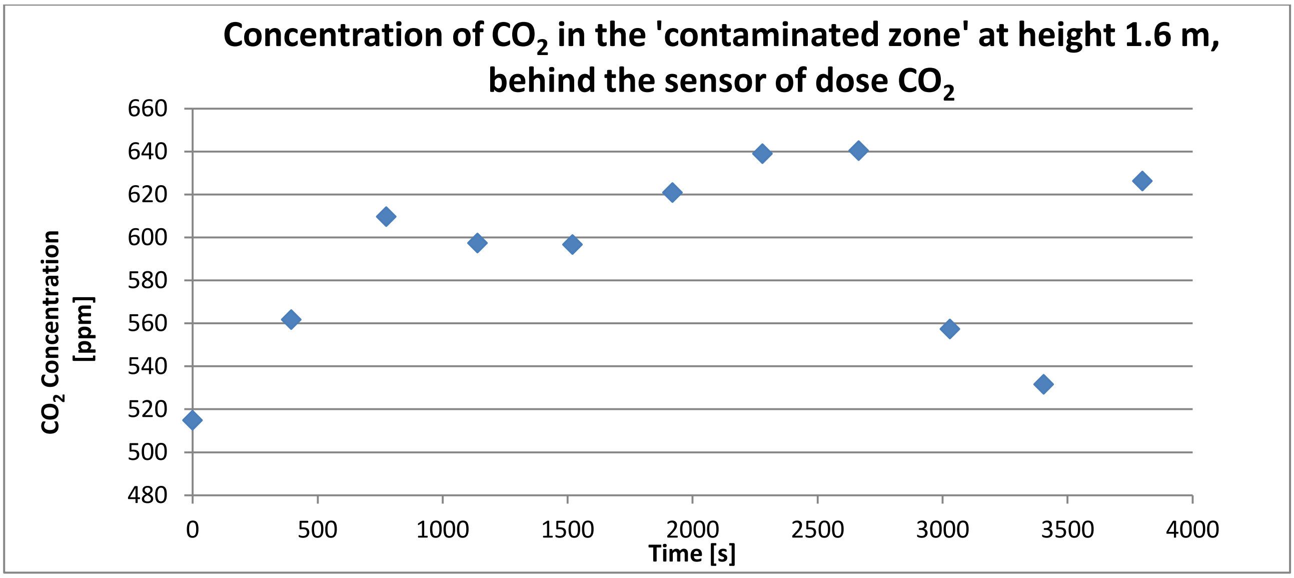
Concentration of CO_2 in the 'protected zone' at height 1.6 m			
No.	Time		CO2 concentration
	hh:mm:ss	s	ppm
1	05:12:55	0	435.14
2	05:19:00	365	441.67
3	05:25:20	745	448.21
4	05:31:40	1125	461.83
5	05:37:45	1490	459.93
6	05:44:20	1885	460.1
7	05:50:45	2270	466.14
8	05:56:50	2635	463.31
9	06:03:05	3010	467.11
10	06:09:10	3375	467.3



Graph 50. Concentration of CO_2 in the 'protected zone' at height 1.1 m – series no. 4 case no. 4.3

Table 58. Tabular listing of CO_2 concentration CO_2 in the 'protected zone' at height 1.1 m – series no. 4 case no. 4.3

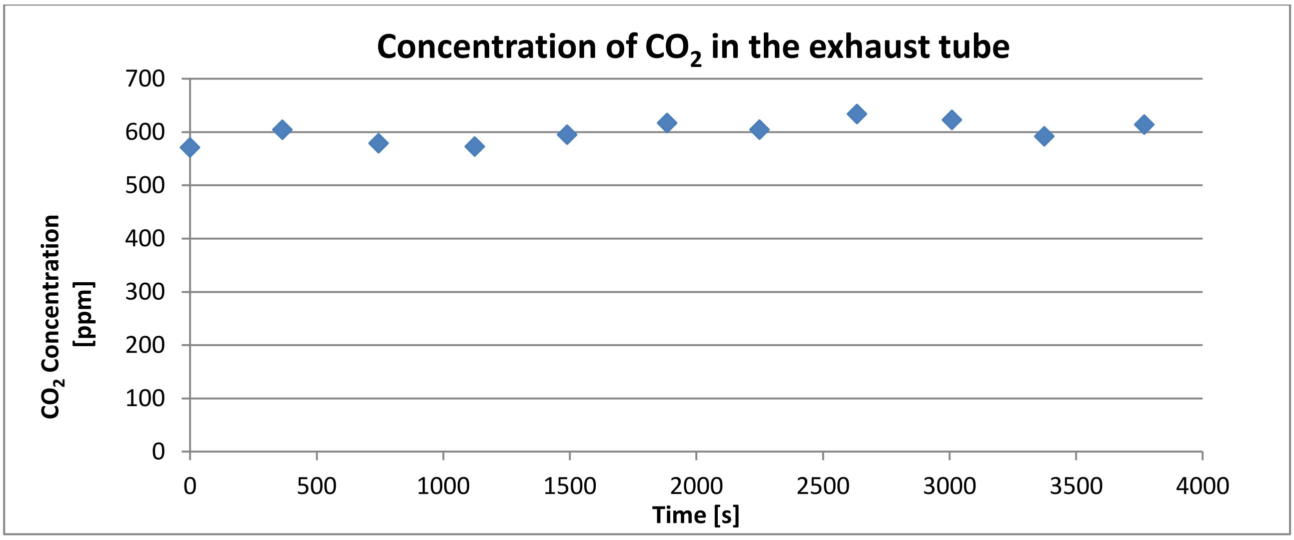
Concentration of CO_2 in the 'protected zone' at height 1.1 m			
No.	Time		CO2 concentration
	hh:mm:ss	s	ppm
1	05:14:55	0	434.95
2	05:21:15	380	437.82
3	05:27:20	745	450.24
4	05:33:40	1125	437.17
5	05:39:45	1490	451.84
6	05:46:20	1885	447.77
7	05:52:45	2270	483.13
8	05:58:50	2635	447.89
9	06:05:05	3010	452.82
10	06:11:40	3405	458.33



Graph 51. Concentration of CO_2 in the 'contaminated zone' at height 1.6 m, behind the sensor of dose CO_2 – series no. 4 case no. 4.3

Table 59. Tabular listing of CO2 concentration in the 'contaminated zone' at height 1.6 m, behind the sensor of dose CO_2 – series no. 4 case no. 4.3

Contaminated zone -1.6m behind the sensor of dose CO_2			
No.	Time		CO2 concentration
	hh:mm:ss	s	ppm
1	05:09:20	0	514.92
2	05:15:55	395	561.8
3	05:22:15	775	609.74
4	05:28:20	1140	597.44
5	05:34:40	1520	596.73
6	05:41:20	1920	620.94
7	05:47:20	2280	639.05
8	05:53:45	2665	640.47
9	05:59:50	3030	557.42
10	06:06:05	3405	531.66
11	06:12:40	3800	626.31

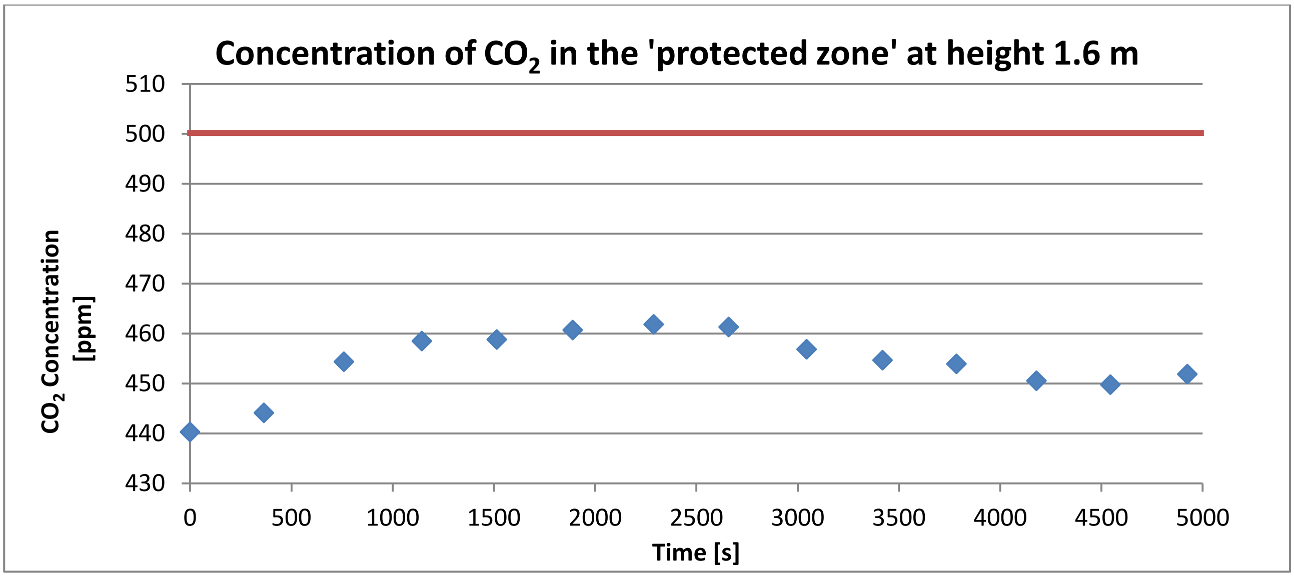


Graph 52. Concentration of CO_2 in the exhaust tube – series no. 4 case no. 4.3

Table 60. Tabular listing of CO2 concentration in the exhaust tube – series no. 4 case no. 4.3

Concentration of CO_2 in the exhaust tube			
No.	Time		CO2 concentration
	hh:mm:ss	s	ppm
1	05:11:50	0	571.25
2	05:17:55	365	604.55
3	05:24:15	745	579.13
4	05:30:35	1125	573.00
5	05:36:40	1490	595.25
6	05:43:15	1885	617.23
7	05:49:20	2250	604.66
8	05:55:45	2635	634.08
9	06:02:00	3010	623.08
10	06:08:05	3375	592.14
11	06:14:40	3770	614.17

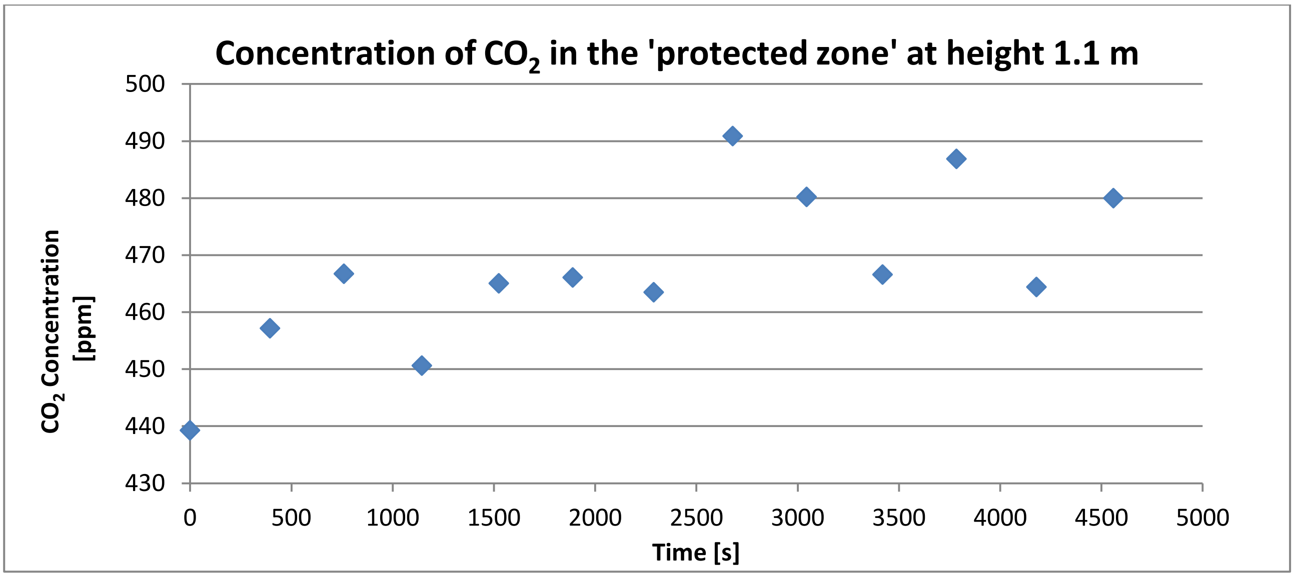
- **Case No. 4.4**



Graph 53. Concentration of CO_2 in the 'protected zone' at height 1.6 m - series no. 4 case no. 4.4

Table 61. Tabular listing of CO2 concentration in the 'protected zone' at height 1.6 m - series no. 4 case no. 4.4

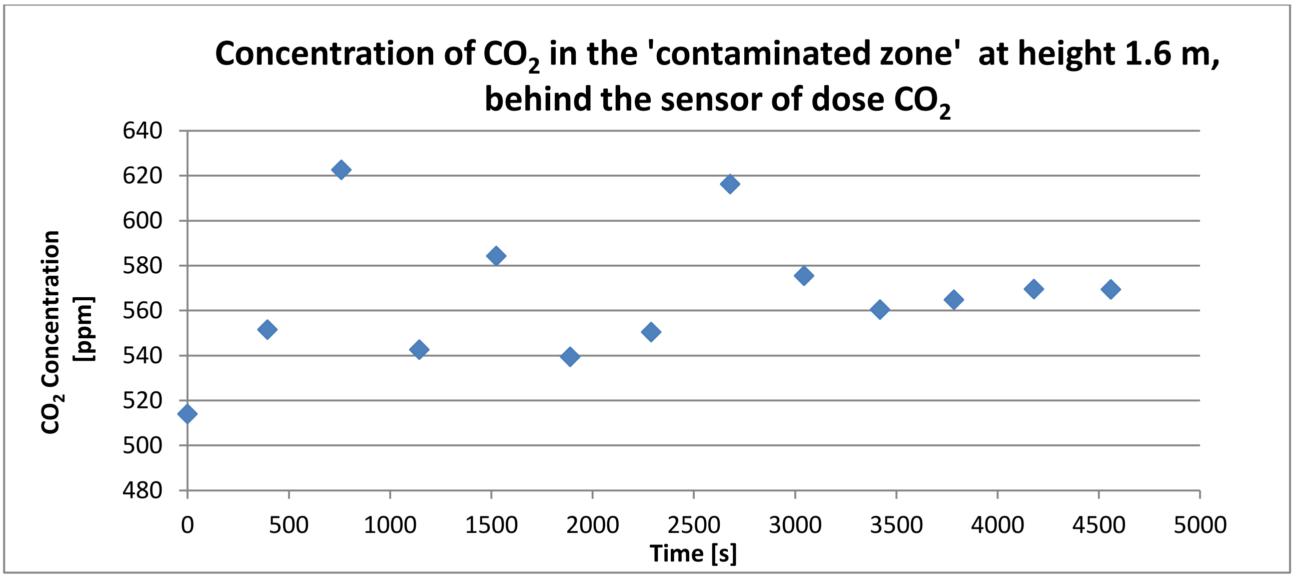
Concentration of CO_2 in the 'protected zone' at height 1.6 m			
No.	Time		CO2 concentration
	hh:mm:ss	s	ppm
1	06:42:22	0	440.30
2	06:48:27	365	444.13
3	06:55:02	760	454.38
4	07:01:27	1145	458.52
5	07:07:37	1515	458.83
6	07:13:52	1890	460.73
7	07:20:32	2290	461.86
8	07:26:42	2660	461.34
9	07:33:07	3045	456.87
10	07:39:22	3420	454.69
11	07:45:27	3785	453.95
12	07:52:02	4180	450.56
13	07:58:07	4545	449.78
14	08:04:27	4925	451.89



Graph 54. Concentration of CO_2 in the 'protected zone' at height 1.1 m – series no. 4 case no. 4.4

Table 62. Tabular listing of CO_2 concentration in the 'protected zone' at height 1.1 m – series no. 4 case no. 4.4

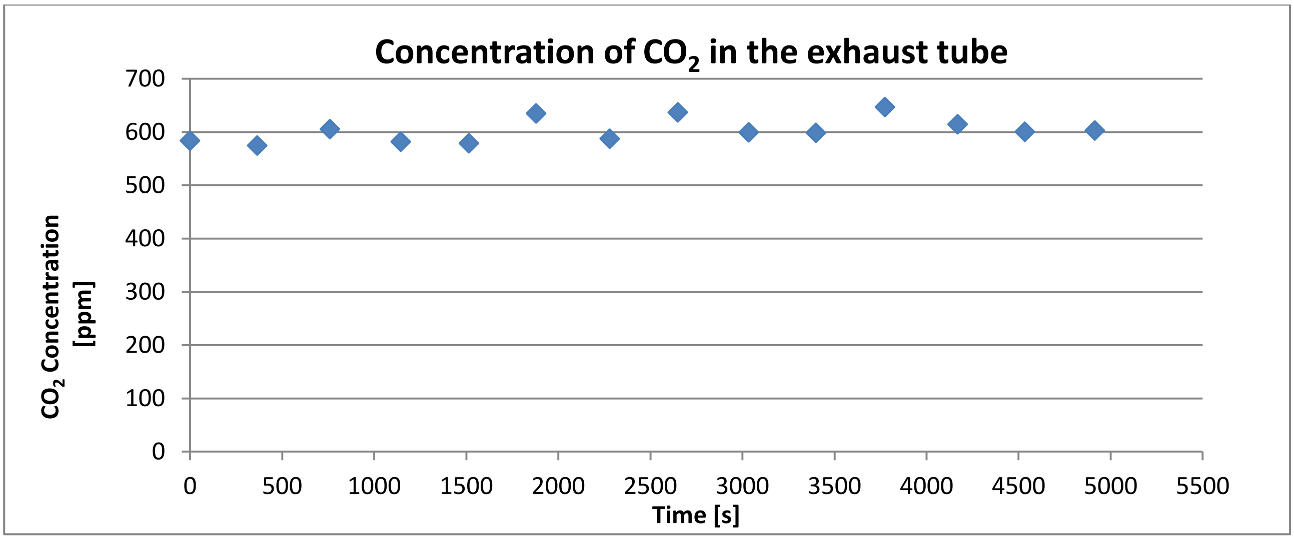
Concentration of CO_2 in the 'protected zone' at height 1.1 m			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	06:44:22	0	439.29
2	06:50:57	395	457.19
3	06:57:02	760	466.75
4	07:03:27	1145	450.64
5	07:09:47	1525	465.07
6	07:15:52	1890	466.10
7	07:22:32	2290	463.51
8	07:29:02	2680	490.90
9	07:35:07	3045	480.23
10	07:41:22	3420	466.61
11	07:47:27	3785	486.90
12	07:54:02	4180	464.43
13	08:00:22	4560	480.01



Graph 55. Concentration of CO_2 in the 'contaminated zone' at height 1.6 m, behind the sensor of dose CO_2 – series no. 4 case no. 4.4

Table 63. Tabular listing of CO_2 concentration in the 'contaminated zone' at height 1.6 m, behind the sensor of dose CO_2 – series no. 4 case no. 4.4

Contaminated zone -1.6m behind the sensor of dose CO_2			
No.	Time		CO2 concentration
	hh:mm:ss	s	ppm
1	06:45:22	0	514.06
2	06:51:57	395	551.57
3	06:58:02	760	622.64
4	07:04:27	1145	542.66
5	07:10:47	1525	584.32
6	07:16:52	1890	539.47
7	07:23:32	2290	550.48
8	07:30:02	2680	616.3
9	07:36:07	3045	575.52
10	07:42:22	3420	560.48
11	07:48:27	3785	564.86
12	07:55:02	4180	569.61
13	08:01:22	4560	569.45

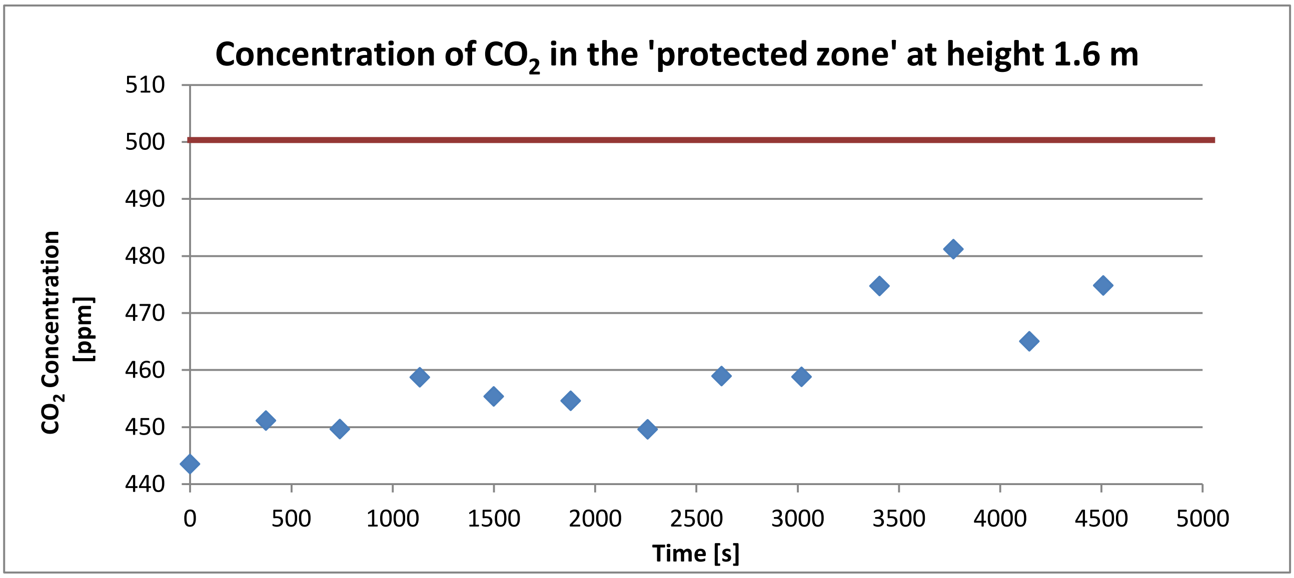


Graph 56. Concentration of CO_2 in the exhaust tube – series no. 4 case no. 4.4

Table 64. Tabular listing of CO_2 concentration in the exhaust tube – series no. 4 case no. 4.4

Concentration of CO_2 in the exhaust tube			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	06:41:17	0	583.99
2	06:47:22	365	574.86
3	06:53:57	760	605.70
4	07:00:22	1145	582.08
5	07:06:32	1515	579.13
6	07:12:47	1880	635.16
7	07:19:27	2280	587.66
8	07:25:37	2650	637.13
9	07:32:02	3035	599.68
10	07:38:07	3400	598.70
11	07:44:22	3775	647.14
12	07:50:57	4170	614.77
13	07:57:02	4535	600.72
14	08:03:22	4915	603.07

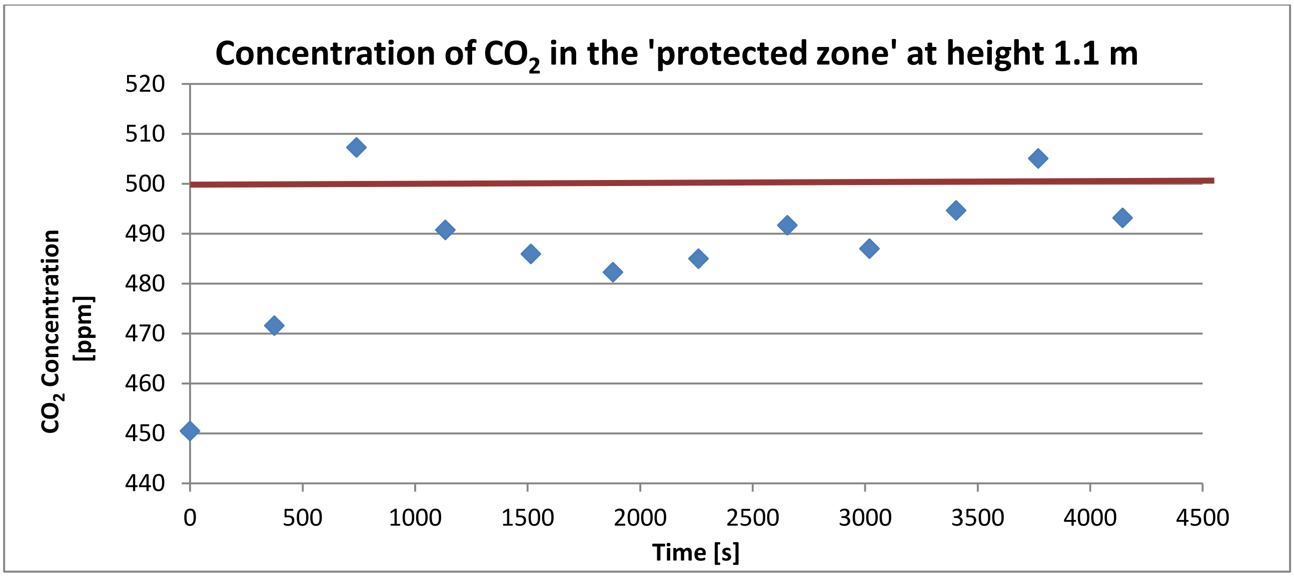
- **Case No. 4.5**



Graph 57. Concentration of CO_2 in the 'protected zone' at height 1.6 m – series no. 4 case no. 4.5

Table 65. Tabular listing of CO_2 concentration in the 'protected zone' at height 1.6 m – series no. 4 case no. 4.5

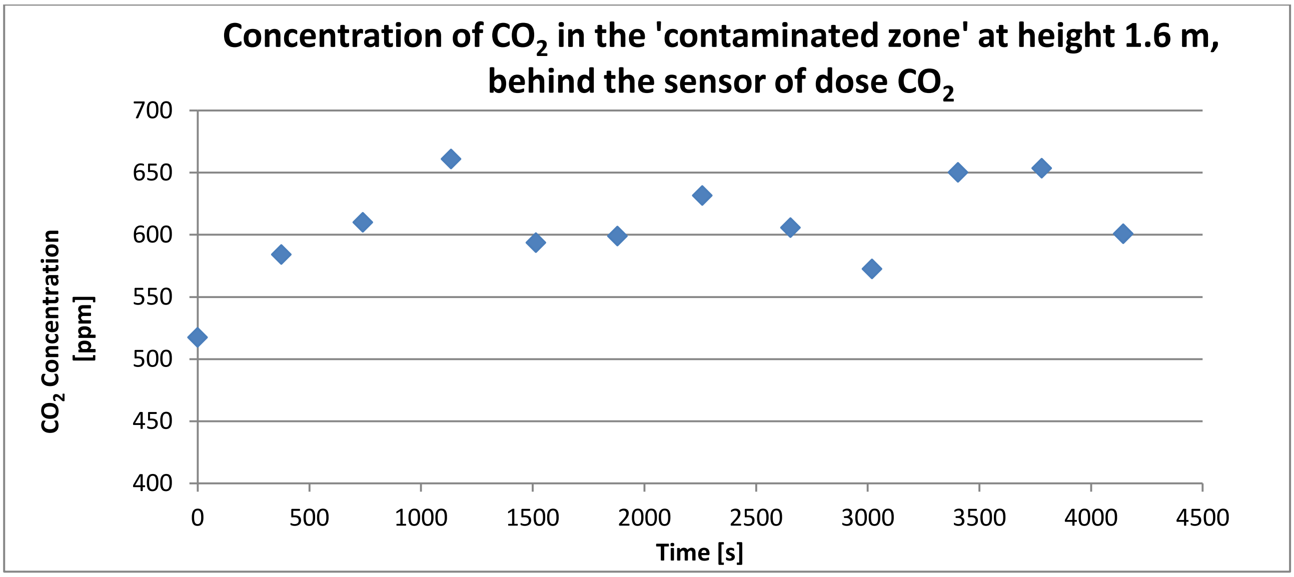
Concentration of CO_2 in the 'protected zone' at height 1.6 m			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	04:49:49	0	443.54
2	04:56:04	375	451.16
3	05:02:09	740	449.67
4	05:08:44	1135	458.75
5	05:14:49	1500	455.39
6	05:21:09	1880	454.63
7	05:27:29	2260	449.62
8	05:33:34	2625	458.96
9	05:40:09	3020	458.83
10	05:46:34	3405	474.76
11	05:52:39	3770	481.22
12	05:58:54	4145	465.06
13	06:04:59	4510	474.85



Graph 58. Concentration of CO_2 in the 'protected zone' at height 1.1 m – series no. 4 case 4.5

Table 66. Tabular listing of CO_2 concentration in the 'protected zone' at height 1.1 m – series no. 4 case 4.5

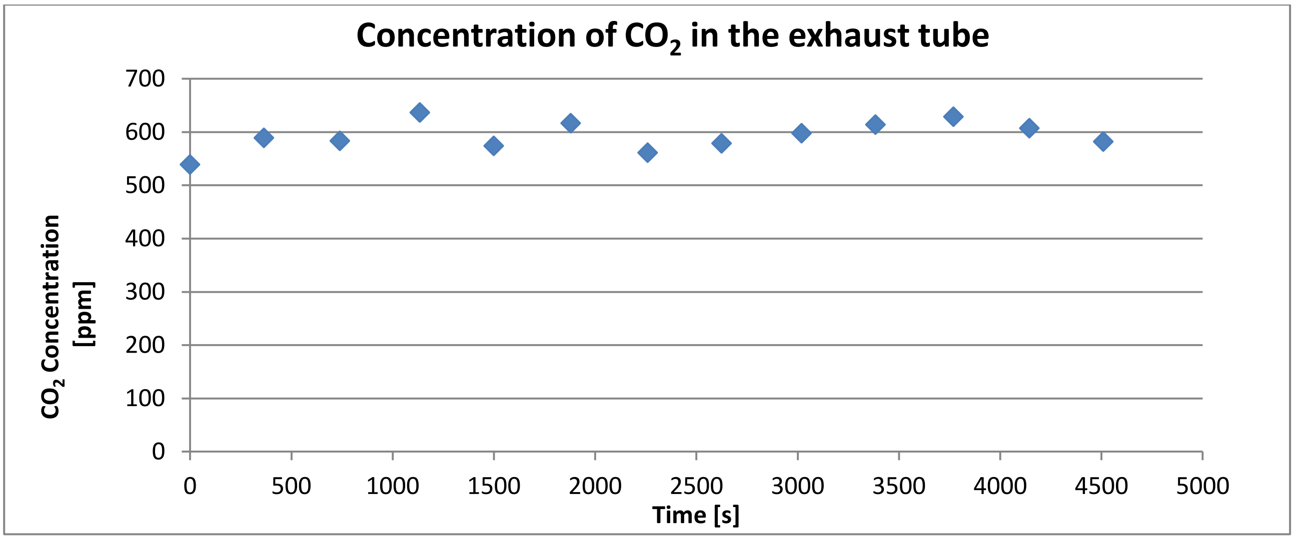
Concentration of CO_2 in the 'protected zone' at height 1.1 m			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	04:51:49	0	450.49
2	04:58:04	375	471.60
3	05:04:09	740	507.31
4	05:10:44	1135	490.78
5	05:17:04	1515	485.97
6	05:23:09	1880	482.31
7	05:29:29	2260	485.02
8	05:36:04	2655	491.72
9	05:42:09	3020	487.03
10	05:48:34	3405	494.69
11	05:54:39	3770	505.10
12	06:00:54	4145	493.20



Graph 59. Concentration of CO_2 in the 'contaminated zone' at height 1.6 m, behind the sensor of dose CO_2 – series no. 4 case no. 4.5

Table 67. Tabular listing of CO_2 concentration in the 'contaminated zone' at height 1.6 m, behind the sensor of dose CO_2 – series no. 4 case no. 4.5

Contaminated zone -1.6m behind the sensor of dose CO_2			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	04:52:49	0	517.51
2	04:59:04	375	584.21
3	05:05:09	740	610.13
4	05:11:44	1135	661.13
5	05:18:04	1515	593.78
6	05:24:09	1880	599.08
7	05:30:29	2260	631.72
8	05:37:04	2655	605.86
9	05:43:09	3020	572.62
10	05:49:34	3405	650.36
11	05:55:49	3780	653.70
12	06:01:54	4145	600.94

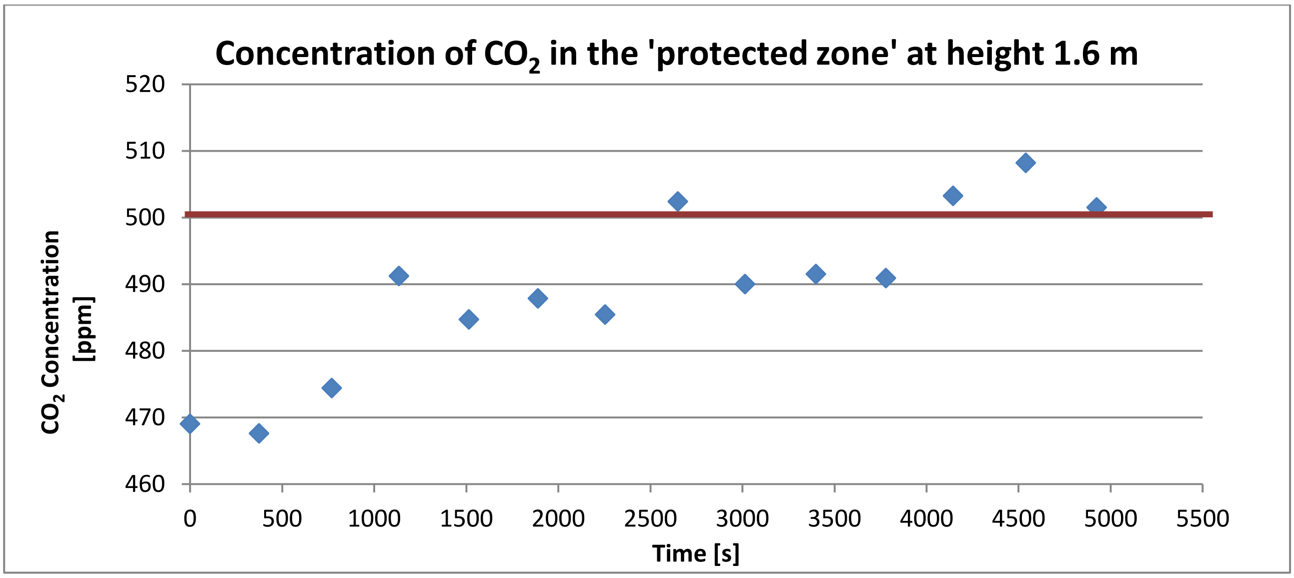


Graph 60. Concentration of CO_2 in the exhaust tube – series no. 4 case no. 4.5

Table 68. Tabular listing of CO_2 concentration in the exhaust tube – series no. 4 case no. 4.5

Concentration of CO_2 in the exhaust tube			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	04:48:44	0	539.26
2	04:54:49	365	589.3
3	05:01:04	740	583.72
4	05:07:39	1135	636.91
5	05:13:44	1500	574.26
6	05:20:04	1880	616.85
7	05:26:24	2260	561.47
8	05:32:29	2625	579.02
9	05:39:04	3020	598.02
10	05:45:09	3385	614.17
11	05:51:34	3770	628.99
12	05:57:49	4145	607.45
13	06:03:54	4510	582.24

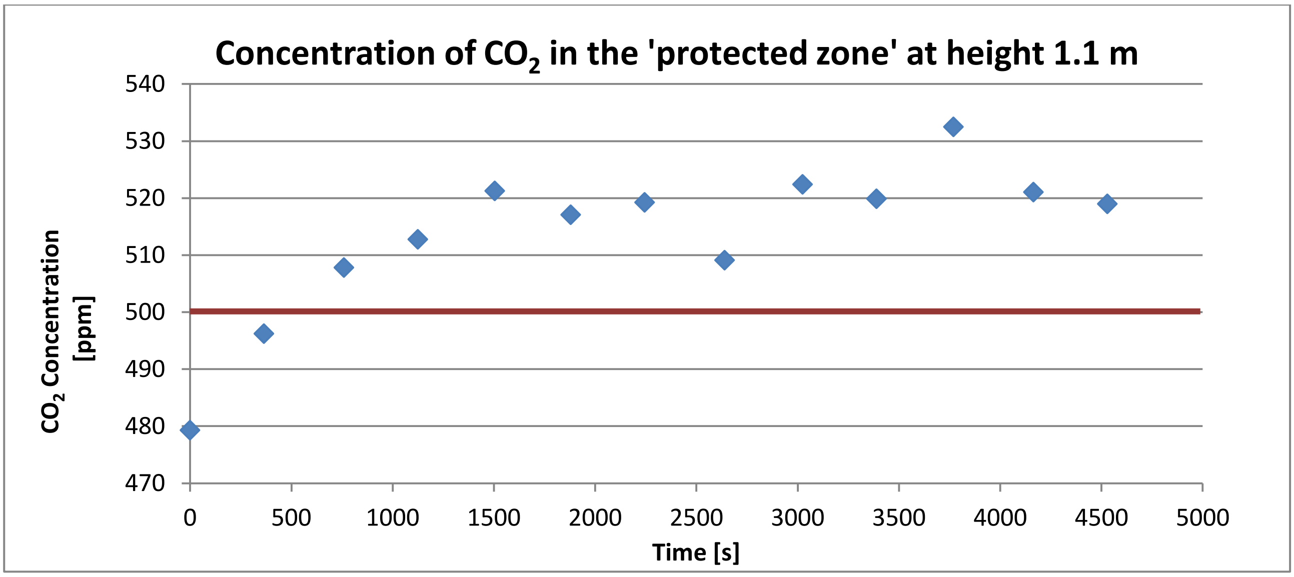
- **Case No. 4.6**



Graph 61. Concentration of CO_2 in the 'protected zone' at height 1.6 m – series no. 4 case no. 4.6

Table 69. Tabular listing of CO_2 concentration in the 'protected zone' at height 1.6 m – series no. 4 case no. 4.6

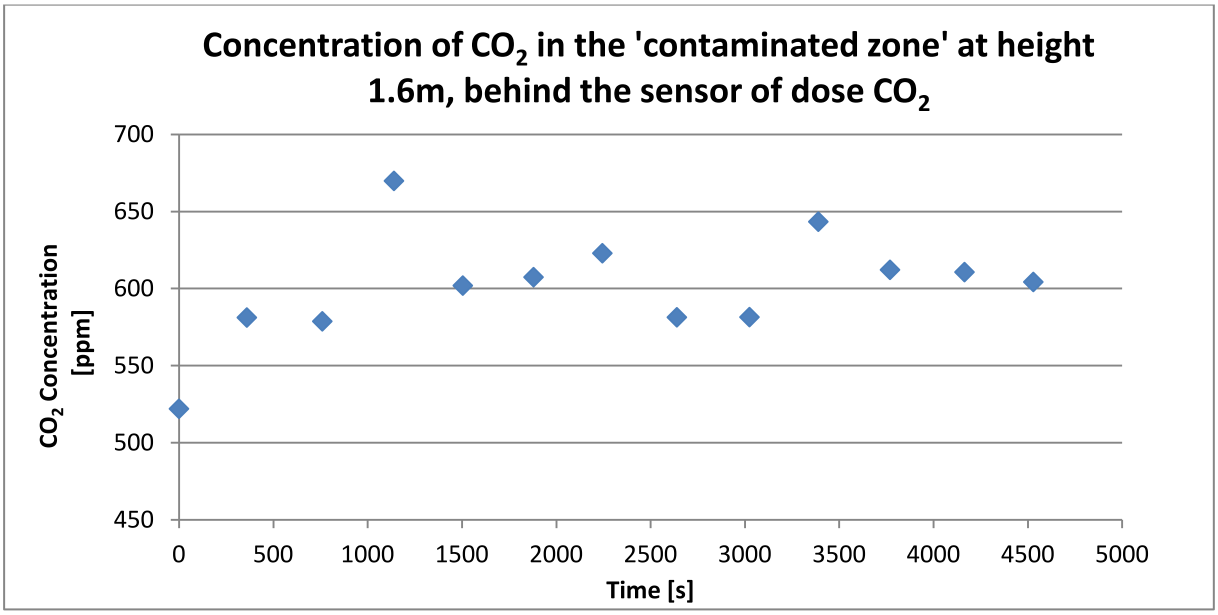
Concentration of CO_2 in the 'protected zone' at height 1.6 m			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	09:24:26	0	469.06
2	09:30:41	375	467.63
3	09:37:16	770	474.43
4	09:43:21	1135	491.24
5	09:49:41	1515	484.73
6	09:55:56	1890	487.88
7	10:02:01	2255	485.46
8	10:08:36	2650	502.42
9	10:14:41	3015	490.03
10	10:21:06	3400	491.54
11	10:27:26	3780	490.93
12	10:33:31	4145	503.27
13	10:40:06	4540	508.22
14	10:46:31	4925	501.53



Graph 62. Concentration of CO_2 in the 'protected zone' at height 1.1 m – series no. 4 case no. 4.6

Table 70. Tabular listing of CO_2 concentration in the 'protected zone' at height 1.1 m – series no. 4 case no. 4.6

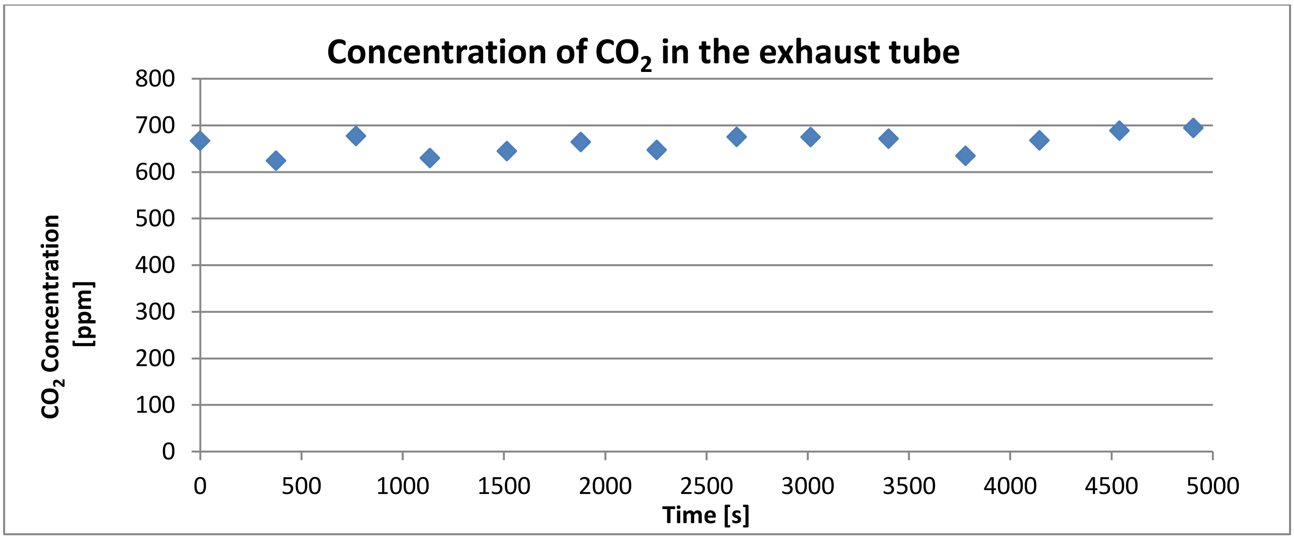
Concentration of CO_2 in the 'protected zone' at height 1.1 m			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	09:26:36	0	479.32
2	09:32:41	365	496.25
3	09:39:16	760	507.84
4	09:45:21	1125	512.79
5	09:51:41	1505	521.28
6	09:57:56	1880	517.10
7	10:04:01	2245	519.27
8	10:10:36	2640	509.13
9	10:17:01	3025	522.43
10	10:23:06	3390	519.90
11	10:29:26	3770	532.51
12	10:36:01	4165	521.07
13	10:42:06	4530	519.01



Graph 63. Concentration of CO_2 in the 'contaminated zone' at height 1.6m, behind the sensor of dose CO_2 – series no. 4 case no. 4.6

Table 71. Tabular listing of CO_2 concentration in the 'contaminated zone' at height 1.6m, behind the sensor of dose CO_2 – series no. 4 case no. 4.6

Contaminated zone -1.6m behind the sensor of dose CO2			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	09:27:37	0	522.08
2	09:33:37	360	581.26
3	09:40:17	760	578.80
4	09:46:37	1140	669.88
5	09:52:42	1505	601.98
6	09:58:57	1880	607.45
7	10:05:02	2245	622.97
8	10:11:37	2640	581.42
9	10:18:02	3025	581.53
10	10:24:07	3390	643.42
11	10:30:27	3770	612.20
12	10:37:02	4165	610.73
13	10:43:07	4530	604.33



Graph 64. Concentration of CO_2 in the exhaust tube – series no. 4 case no. 4.6

Table 72. Tabular listing of CO_2 concentration in the exhaust tube – series no. 4 case no. 4.6

Concentration of CO_2 in the exhaust tube			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	09:23:22	0	667.2
2	09:29:37	375	624.56
3	09:36:12	770	677.48
4	09:42:17	1135	630.24
5	09:48:37	1515	645.11
6	09:54:42	1880	664.58
7	10:00:57	2255	647.52
8	10:07:32	2650	675.62
9	10:13:37	3015	675.24
10	10:20:02	3400	671.79
11	10:26:22	3780	634.95
12	10:32:27	4145	668.13
13	10:39:02	4540	689.02
14	10:45:07	4905	694.81

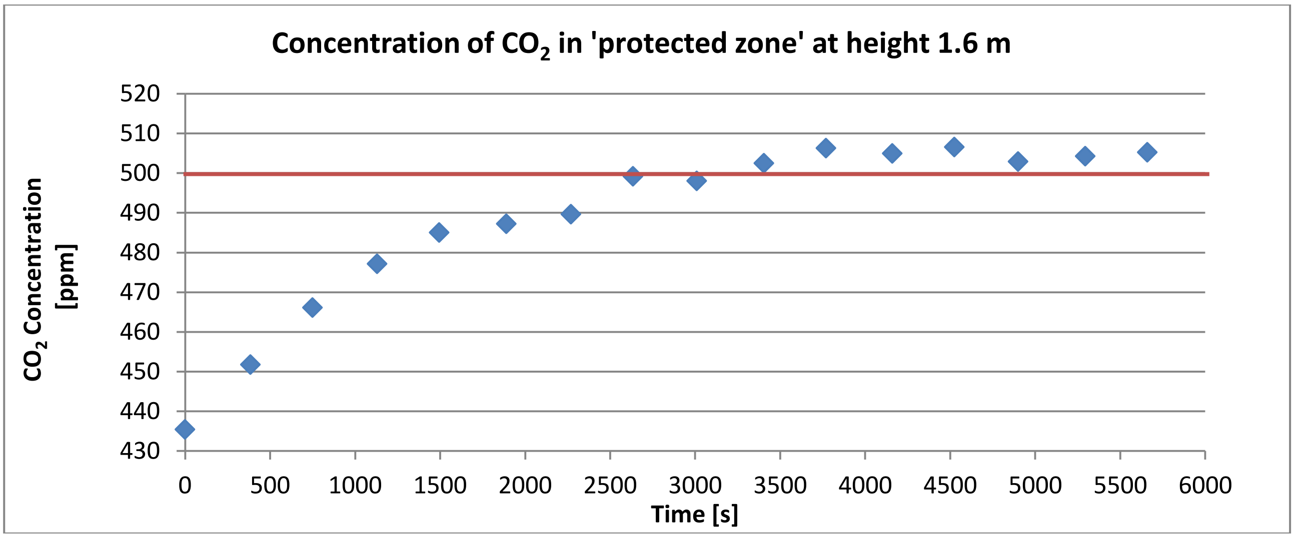
The series no. 4 is the last part of a main measurement of CO_2 concentration and probably it is the most important part. Series no. 4 consists of six cases. In cases no 4.1, 4.2, 4.3 and 4.4, the parameters of the plane jet and exhaust airflow rates can separate the protected zone from the contaminated zone. In two other cases (no. 4.5 and no. 4.6) the plane jet does not prevent the transmission of pollutants from the polluted zone to the protected zone. After analyzing the measurements of CO_2 concentration found that the most appropriate for this experimental study is case no. 4.4. The most effective measurement conditions of CO_2 concentration, namely the supply airflow and the exhaust airflow are equal to q_{sup}=78 m^3/h , q_{exh}=310 m^3/h. The readings of series no. 4 from various sampling points tend to kept on the stable, constants level what may be

considered as a advantage this ventilation system. A major importance has a systematic, regular work of layouts, resistant to unfavorable impact of factors, such as draft or activity of occupants. As can been seen on Graph 41,Graph 42 in case 4.1 and also on Graph 45,Graph 46 in case 4.2 the result of contaminant concentration is kept at a uniformly low level in protected zone. Moreover considering the measurement results can be conclude that together with reducing volume supply air decreases the turbulence of airflow which affects to possibilities for improvement of the performance of methods reducing infection risk. Comparing the case no. 4.4 and 4.5, found that a limit value is in the range 250 m^3/h to 310 m^3/h. As shows Graph 58 the boundary of CO_2 concentration was exceeded only two times in case 4.5. Therefore, it can be stated that the minimal sufficient value of exhaust air to protect zone by using the air curtain is close to 250 m^3/h. In order to show a significant overrunning the threshold value of CO_2 concentration carried out the case no. 4.6. Difference between measurement conditions is greatly slight, namely volume of extract air is smaller than
30 m^3/h. The exceeded values of concentration are kept at the average level of 515 ppm at height 1.1 m and at the level of 490 ppm at height 1.6 in the protected zone.

Very interesting a objective of study could be also the case no. 4.1. In this case both of zones are protected, it means that the concentration of CO_2 in polluted zone was reduced to less than 500 ppm. In this conditions the exposure of residence occupants in contaminated zone such as waiting patients to impact the of infectious diseases was also decreased. The smaller contamination in polluted zone is probably due to less mixing of air masses and the less turbulence airflow of a plane jet.

Should also be noted that during of CO_2 measurement, the concentrations in exhaust tube are kept on high level. In fact, this operations is highly desirable because clearly identify this to a high efficiency of removing indoor pollutions.

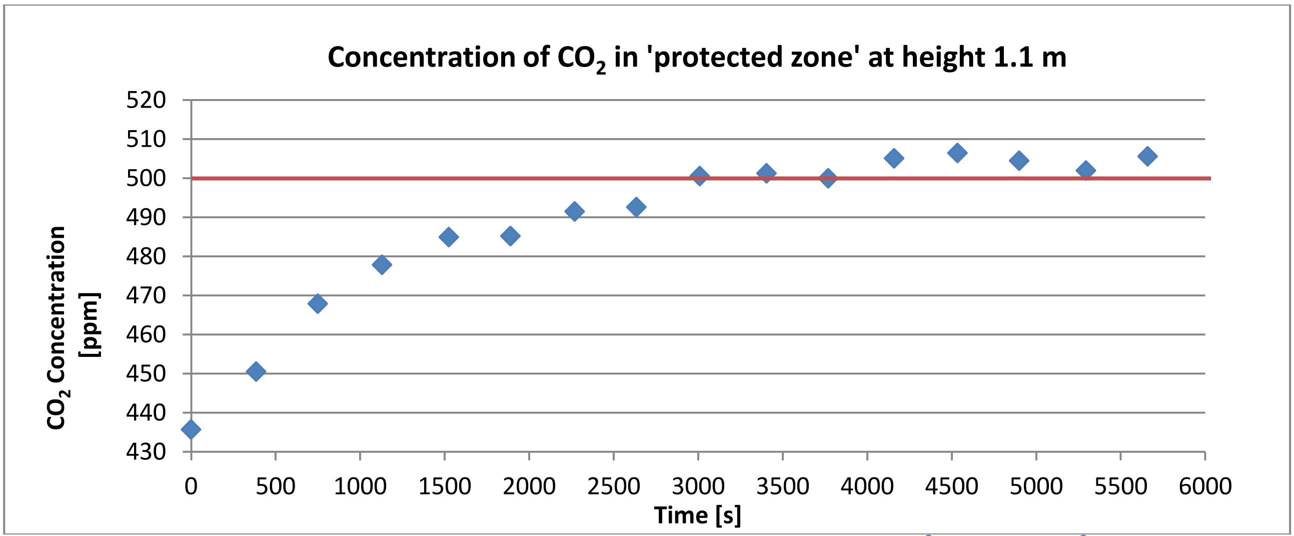
As already mentioned, in this report will be show one case with dimensions of outlet opening for which it is possible to prevent entry of contaminants from target zone to protected zone. Below, was shown an example which presents the limit values for which the protected zone is protected and for which no protected. In this case the dimensions of exhaust opening are equal to 0.03 m –width and 1.0 m – length. With these results can be seen, that the minimum area of outlet nozzle should be equal to 0.04 m2. For this case are created two types of graph. One of them shows the CO2 concentration in protected zone at 1.6 m (
Graph 65) and the second one at height 1.1 m (Graph 66.



Graph 65. Concentration of CO_2 in 'protected zone' at height 1.6 m in case where q_{sup}= 78 m^3/h, q_{exh}=310 m^3/h, effective area =0.03 m^2

Table 73. Tabular listing of CO_2 concentration in 'protected zone' at height 1.6 m in case where q_{sup}= 78 m^3/h, q_{exh}=310 m^3/h, effective area =0.03 m^2

Concentration of CO_2 in 'protected zone' at height 1.6 m			
No.	Time		CO_2 Concentration
	hh:mm:ss	s	ppm
1	14:48:05	0	435.46
2	14:54:30	385	451.80
3	15:00:35	750	466.16
4	15:06:55	1130	477.19
5	15:13:00	1495	485.07
6	15:19:35	1890	487.27
7	15:25:55	2270	489.69
8	15:32:00	2635	499.23
9	15:38:15	3010	498.08
10	15:44:50	3405	502.53
11	15:50:55	3770	506.33
12	15:57:25	4160	504.99
13	16:03:30	4525	506.60
14	16:09:45	4900	502.95
15	16:16:20	5295	504.30
16	16:22:25	5660	505.28



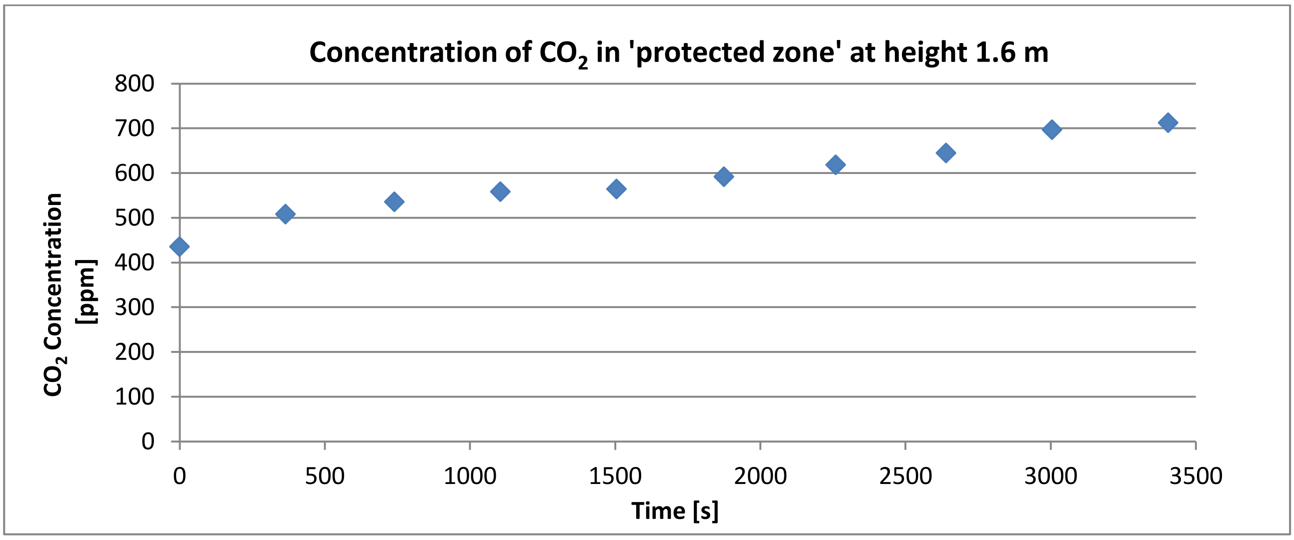
Graph 66. Concentration of CO_2 in 'protected zone' at height 1.1 m in case where q_{sup}= 78 m^3/h, q_{exh}=310 m^3/h, effective area =0.03 m^2

Table 74. Tabular listing of CO_2 concentration in 'protected zone' at height 1.1 m in case where q_{sup}= 78 m^3/h, q_{exh}=310 m^3/h, effective area =0.03 m^2

Concentration of CO_2 in 'protected zone' at height 1.1 m			
No.	Time		CO_2 Concentration
	hh:mm:ss	s	ppm
1	14:49:05	0	435.75
2	14:55:30	385	450.56
3	15:01:35	750	467.94
4	15:07:55	1130	477.90
5	15:14:30	1525	484.98
6	15:20:35	1890	485.25
7	15:26:55	2270	491.54
8	15:33:00	2635	492.66
9	15:39:15	3010	500.59
10	15:45:50	3405	501.30
11	15:51:55	3770	500.03
12	15:58:25	4160	505.14
13	16:04:40	4535	506.51
14	16:10:45	4900	504.53
15	16:17:20	5295	502.02
16	16:23:25	5660	505.65

Both of graphs shows the progressive increase of CO_2 concentration. After 50 min the threshold of 500 ppm was exceeded. This measurements were carried out for volume of supply air equal to 78 m^3/h and exhaust airflow equal to 310 m^3/h. Hence, this results could be compare with case 4.4 series 4. The conditions both of cases are very similar, differ only in size of the effective area of outlet opening. Comparing these results it can be noted, that reduced area of exhaust nozzle to 0.03m^2 prevents separation zones and the indoor pollutions penetrates to the protected zone.

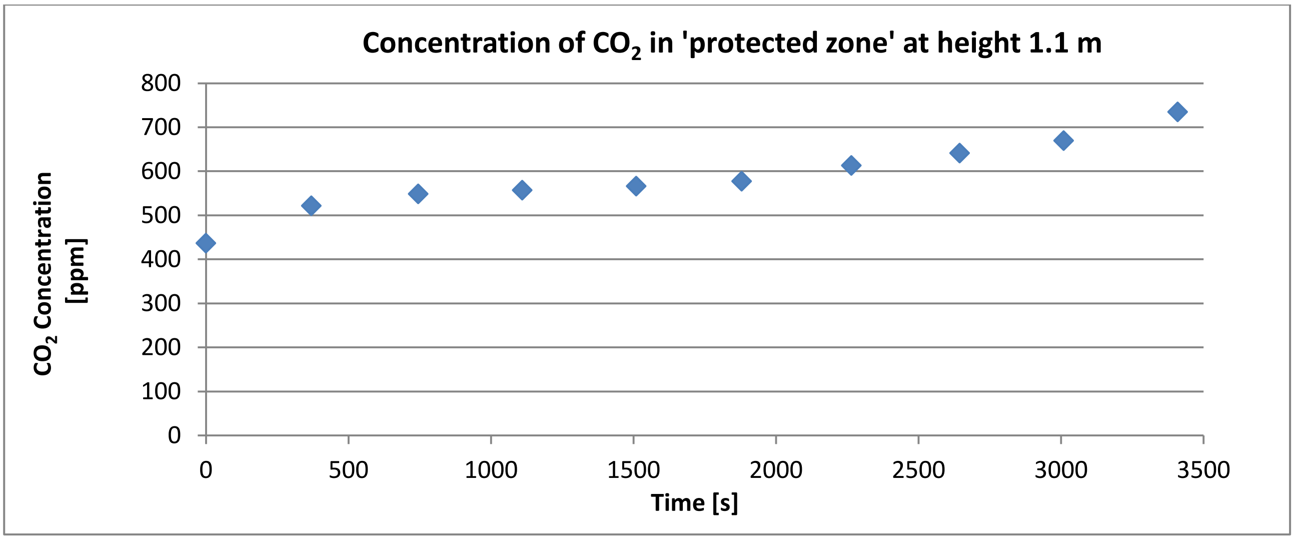
Furthermore, in this report will presents the measurement result of case in which was used only the supply air system. The volume of supply is equal to 78 m^3/h. In this case the exhaust air system was no active. The results of this case show how major importance is to perform the exhaust located near the source of a contamination. For this case will be presented four graphs and tables excluding readings from sampling points in supply tube and probe immediately placed at CO_2 dosing wire. The CO_2 concentration in supply tube and near to CO_2 dosing wire is kept at the same level as in the other cases.



Graph 67. Concentration of CO_2 in 'protected zone' at height 1.6 m in case with active the air curtain and no active the exhaust air system

Table 75. Tabular listing of CO_2 concentration in 'protected zone' at height 1.6 m in case with active the air curtain and no active the exhaust air system

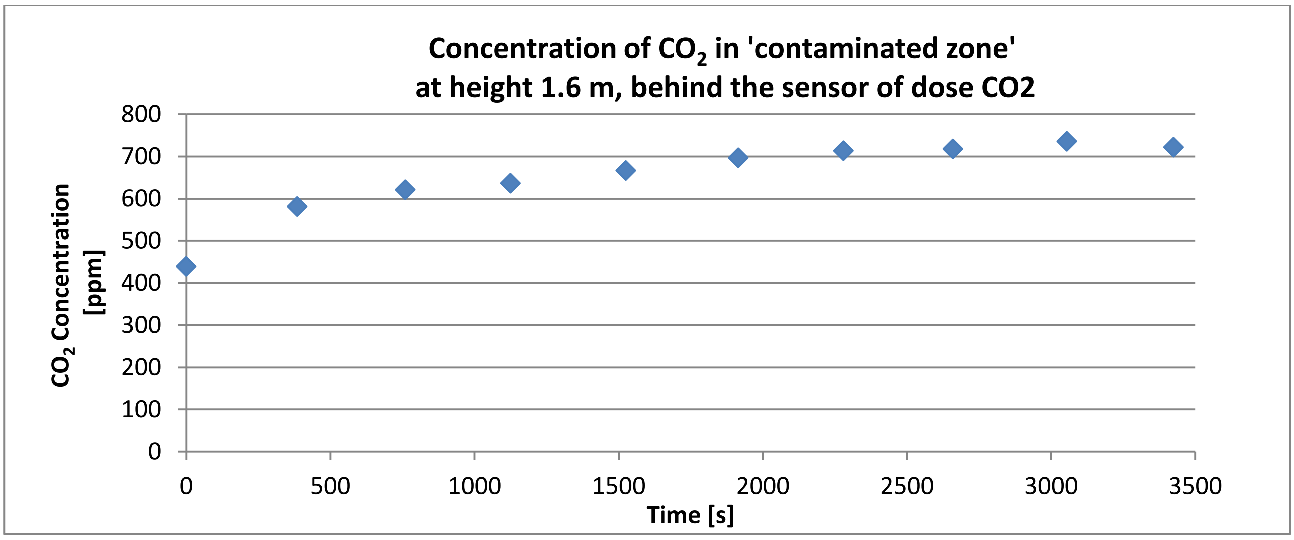
Concentration of CO_2 in 'protected zone' at height 1.6 m			
No.	Time		CO_2 Concentration
	hh:mm:ss	s	ppm
	17:27:49	0	435.78
1	17:33:44	365	508.48
2	17:39:59	740	536.01
3	17:46:04	1105	558.63
4	17:52:44	1505	564.64
5	17:58:54	1875	592.07
6	18:05:19	2260	618.68
7	18:11:39	2640	645.14
8	18:17:44	3005	697.14
9	18:24:24	3405	712.73



Graph 68. Concentration of CO_2 in 'protected zone' at height 1.1 m in case with active the air curtain and no active the exhaust air system

Table 76. Tabular listing of CO_2 concentration in 'protected zone' at height 1.1 m in case with active the air curtain and no active the exhaust air system

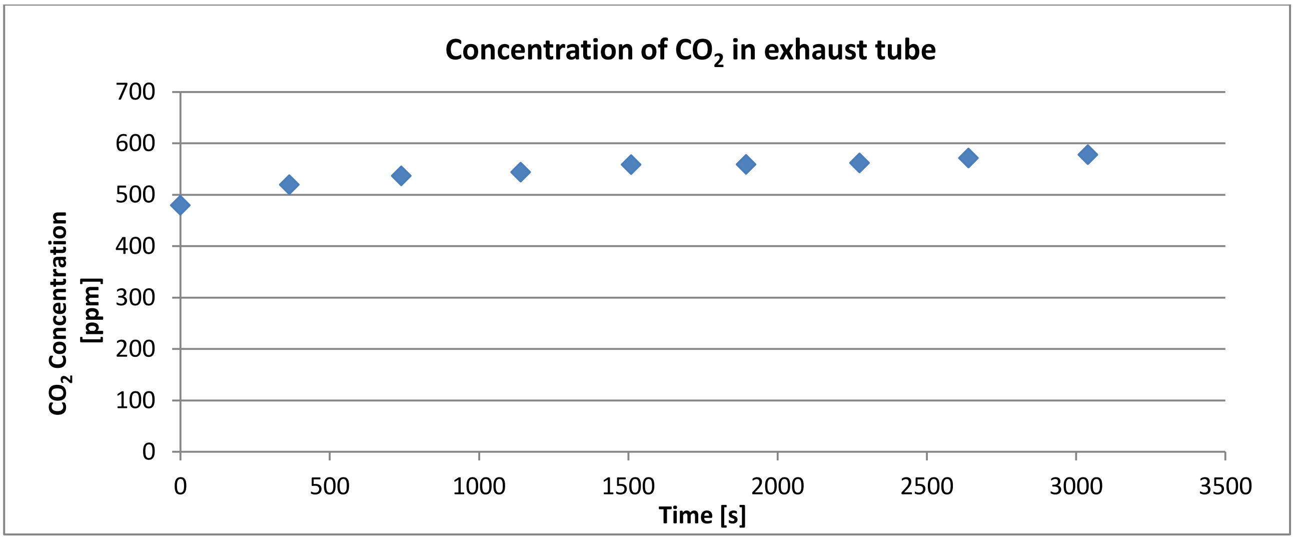
Concentration of CO_2 in 'protected zone' at height 1.1 m			
No.	Time		CO_2 concentration
	hh:mm:ss	s	ppm
1	17:28:34	0	436.98
2	17:34:44	370	521.93
3	17:40:59	745	548.89
4	17:47:04	1110	557.31
5	17:53:44	1510	566.50
6	17:59:54	1880	577.65
7	18:06:19	2265	613.45
8	18:12:39	2645	641.59
9	18:18:44	3010	669.89
10	18:25:24	3410	735.13



Graph 69. Concentration of CO_2 in 'contaminated zone' at height 1.6 m, behind the sensor of dose CO2 in case with active the air curtain and no active the exhaust air system

Table 77. Tabular listing of CO_2 concentration in 'contaminated zone' at height 1.6 m, behind the sensor of dose CO2 in case with active the air curtain and no active the exhaust air system

Contaminated zone -1.6m behind the sensor of dose CO2			
No.	Time		CO_2 Concentration
	hh:mm:ss	s	ppm
1	17:29:19	0	439.55
2	17:35:44	385	581.54
3	17:41:59	760	621.34
4	17:48:04	1125	636.77
5	17:54:44	1525	666.89
6	18:01:14	1915	697.12
7	18:07:19	2280	713.84
8	18:13:39	2660	718.12
9	18:20:14	3055	736.111
10	18:26:24	3425	722.21



Graph 70. Concentration of CO_2 in exhaust tube in case with active the air curtain and no active the exhaust air system

Table 78. Tabular listing of CO_2 concentration in exhaust tube in case with active the air curtain and no active the exhaust air system

Concentration of CO_2 in exhaust tube			
No.	Time		CO_2 Concentration
	hh:mm:ss	s	ppm
1	17:32:44	0	479.70
2	17:38:49	365	519.77
3	17:45:04	740	536.94
4	17:51:44	1140	544.11
5	17:57:54	1510	558.79
6	18:04:19	1895	559.17
7	18:10:39	2275	562.12
8	18:16:44	2640	571.64
9	18:23:24	3040	578.14

This case shows the application of local exhaust is indispensable to divide open space into subzones with at low operating parameters of protect zone ventilation. As shown case no. 4.4 series 4, for the same values of supply airflow rate but with using the exhaust air system efficiently reduce the exposure of reside workers in protected zone to the indoor pollution. Without using exhaust air system, the downward plane jet is not able to block the transmission of contamination into protected zones. Lack of exhaust air system causes a high concentration of CO_2 in the protect zone reaching level of 722 ppm.

In order to shows the greatest number of factor which characterize obtained results, was carried out simple calculation of efficiency of the ventilation system. To specify the values of airflow patterns used following formulas:

$$\eta_s = \frac{C_s}{C_e} = \frac{\Delta C_{target\ zone} - \Delta C_{protect\ zone}}{\Delta C_{target\ zone}} \cdot 100\ [\%]$$

where:

$\eta_s -$ *separation effectiveness*, %

$C_s -$ *the amount of stopped contamination, ppm*

$C_e -$ *the entire amount of contamination, ppm*

$\Delta C_{target\ zone} -$ *the amount of contamination in target zone, ppm*

$\Delta C_{protect\ zone} -$ *the amount of contamination in protect zone, ppm*

$$\boldsymbol{\Delta C_{target\ zone} = C_{target\ zone} - C_{supply\ tube}}$$

where:

$C_{target\ zone} -$ *average* CO_2 *concentraion in target zone, ppm*

$C_{supply\ tube} -$ *average* CO_2 *concentraion in supply tube, ppm*

$$\boldsymbol{\Delta C_{protect\ zone} = C_{protect\ zone} - C_{supply\ tube}}$$

where:

$C_{protect\ zone} -$ *average* CO_2 *concentraion in protect zone, ppm*

$C_{supply\ tube} -$ *average* CO_2 *concentraion in supply tube, ppm*

- <u>example of calculation</u>

Conditions :

q_{sup}= 78 m^3/h
q_{exh}= 310 m^3/h
dimensions of outlet opening = 0.04 m x 1.0 m

$C_{target\ zone} = 556.26\ ppm$
$C_{protect\ zone\ at\ 1.6} = 454.13\ ppm$
$C_{protect\ zone\ at\ 1.1} = 467.51\ ppm$
} $C_{protect\ zone} = 460.82\ ppm$
$C_{supply\ tube} = 441.54\ ppm$

$$\Delta C_{target\ zone} = 556.26 - 441.54 = 124.73\ ppm$$

$$\Delta C_{protect\ zone} = 460.82 - 441.54 = 19.28\ ppm$$

$$\eta_s = \frac{124.73 - 19.28}{124.73} \cdot 100$$

$$\boldsymbol{\eta_s = 84.54\%}$$

Table 79. Summary of the results of calculation the separation effectiveness

Exhaust airflow rate [m³/h]	Supply airflow rate [m³/h]			
	78	117	149	172
200	58.12 %			
220	62.32 %			
250	80.44%			
310	84.54%			
375	82.63%	76.0%	60.3%	38.5%
400	82.54%	88.2%	72.1%	71.1%
435	66.14%	75.2%		82.9%

Table 79. Summary of the results of calculation the separation effectiveness presents the results of calculation the separation effectiveness. The values of results informs about at which the efficiency the indoor pollutions were blocked by the downward plane jet.

According to the above-mentioned the ultimate goal for CO2 measurement in chapter Measurement setup, the goal was achieved. Develop an effective design procedure for internal space using protected zone ventilation based on the use of a plane jet, namely air curtain. In case no. 4.4 the internal velocity of slot jet is equal to 2.47 m/s and it is the minimum value of supply air fan which was installed in supply ventilation system. The values of concentration in protected zone are maintained below 500 ppm, at levels of 455 ppm (at height 1.6 m) and 467 ppm (at height 1.1m). Therefore, the measurements of CO2 concentration have been completed after series no. 4. However, in the future, to develop and get a better understanding of the performance of the PZV should be carry out and analyze also the measurement with a internal velocity lower than 2.47 m/s. Perhaps, a further reducing of the internal velocity jet able to divide into two subzones and prevent mixing of air masses between zones. Table 80 presents summary of measurement of CO_2 concentration. By conduced measurement it is possible to determine the range of parameters of supply and exhaust air system for which it is able to perform protect zone ventilation. The red area marks that the values of this parameters are not sufficient to protect the select zone. The blue area means that the values airflow patterns are suitable to performance protect zone ventilation.

Table 80. Summary of results of measurement of CO_2 concentration

Exhaust airflow rate [m³/h]	Supply airflow rate [m³/h]			
	78	117	149	172
200	NO			
220	NO			
250	NO			
310	YES			
375	YES	NO	NO	NO
400	YES	YES	YES	YES
435	YES	YES		YES

5.2. Visualization of the airflow distribution of the downward plane jet and the performance of the protected zone ventilation

After completion the measurement of CO_2 concentration proceeded to conduct the smoke test visualization. The aim of a visualization was to illustrate the airflow distribution of the downward plane jet and to study how the plane jet prevents contaminant transfers from one side to the other side. In addition, through visualization, it was able to show the shape of downward plane jet. To this purpose, the smoke generator provided the smoke gas to supply tube and then was transported to air curtain.

The first case was carried out for the airflow patterns equal to:

- internal velocity of jet 2.47 m/s
- volume of supply air q_{sup}=78 m^3/h
- volume of supply air q_{sup}=78 m^3/h

As can be seen, preset values were considered as the most effective to perform the protected zone ventilation during the measurement of CO_2 concentration.

Figure 31 shows the profile of a plane jet. However, to show the really situation in the test room while the smoke test, the photos were taken in front of the air curtain in polluted zone (Figure 32).

a) b) c)

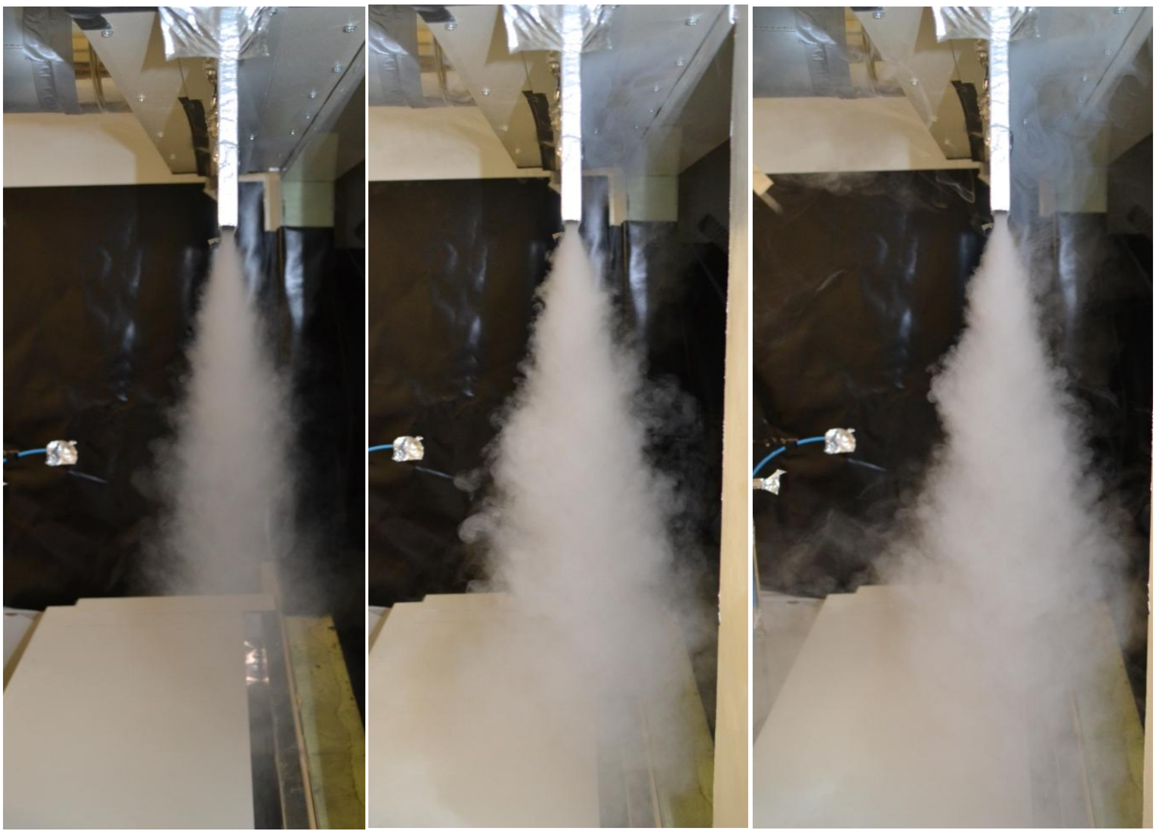


Figure 31. The profile downward plane jet from the air curtain, visualized for case when q_{sup}=78 m^3/h q_{exh}=310 m^3/h effective area =0.04 m^2 a) beginning of smoke test b) center of smoke test c) end of smoke test

Figure 31 presents the profile of jet. The widening angle of jet is equal to29°.

a) b) c)

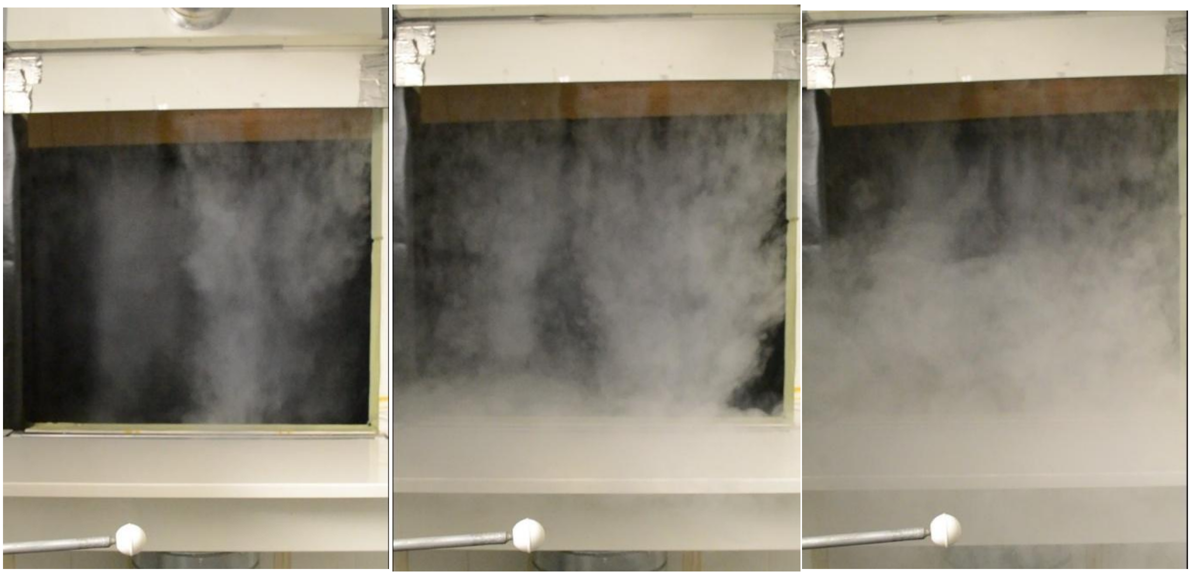


Figure 32. The flow of smoke gas, visualized for case when q_{sup}=78 m^3/h q_{exh}=310 m^3/h effective area =0.04 m^2
a) beginning of smoke test b) center of smoke test c) end of smoke test

As show the Figure 32, a significant amount of supply air is not removed from the test room. The air flows vertically down and then some of it spreads out and litters down on the counter. This process is not desirable because the downward jet of fresh air absorbs the indoor pollution and then mixed with indoor air of zones, transferred the contamination. As described in part Method Section, in this study pursued to design the finally procedure where all downward airflow with pollutants will be removed by exhaust air system. As result, the smoke visualization was also used to specify the airflow which flows vertically downwards and it is completely removed from the experimental chamber.

Therefore, carried out the additional tests under different combinations. It was increased the range of supply and exhaust air and also the dimensions of a outlet opening.

Figure 33 shows the results of smoke test for three difference case. In Table 81 specified the test conditions for each section.

Table 81. Conditions of smoke visualization

Conditions	Section		
	a	b	c
internal velocity [m/s]	3.67	4.57	5.2
q_{sup} [m^3/h]	117	147	173
q_{exh} [m^3/h]	400		
dimensions of outlet opening [m x m]	0.04 x 1.00		

a) b) c)

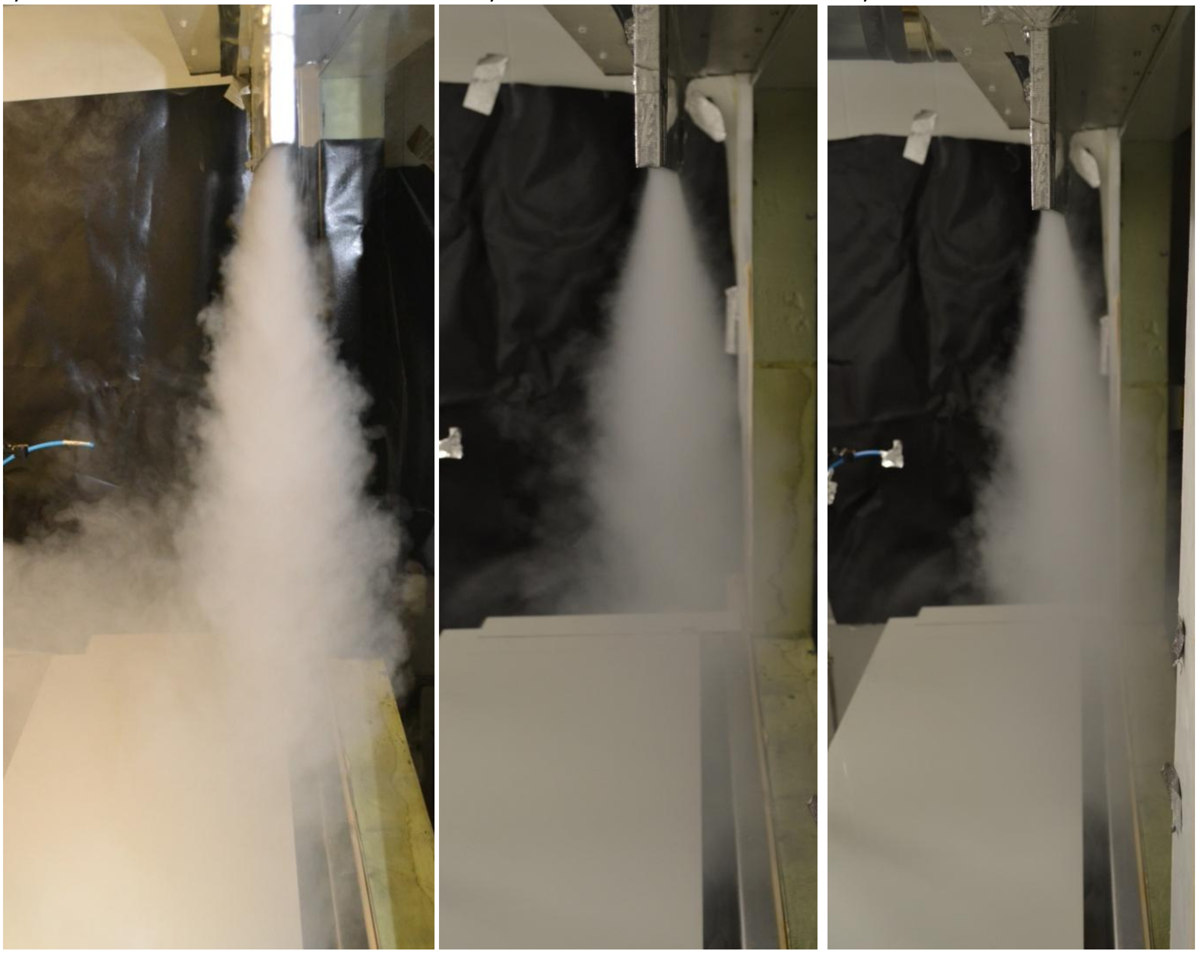


Figure 33. The profile downward plane jet from the air curtain, visualized for case when qexh=310 m3/h effective area =0.04 m2 and a) the supply airflow velocity was 3.67 m/s b) the supply airflow velocity was 4.57 m/s c) the supply airflow velocity was 5.2 m/s

Comparing the profiles of jet can be seen the difference with the widening angle of jet. The most open angle presents the jet of a section *a,* the value of angle is equal to about 29°. In this section the width of a jet is also the largest. For the next section of jet angle gradually decreases, namely for section b is approximately 23° and for section c, the angle decreases to about 17°. As show the results, with the with increasing internal velocity the shape of plane jet is slimmer.

In order to complete the analysis, it should be taken into account real state of the test room (see Figure 34, Figure 35, Figure 36). For each cases presents the three photos. The pictures was taken at the beginning, during and at the end of the visualization.

a) b) c)

Figure 34. The flow of smoke gas, visualized for case when q_{sup}=117 m^3/h q_{exh}=310 m^3/h effective area =0.04 m^2
a) beginning of smoke test b) center of smoke test c) end of smoke test

a) b) c)

Figure 35. The flow of smoke gas, visualized for case when q_{sup}=147 m^3/h q_{exh}=310 m^3/h effective area =0.04 m^2
a) beginning of smoke test b) center of smoke test c) end of smoke test

a) b) c)

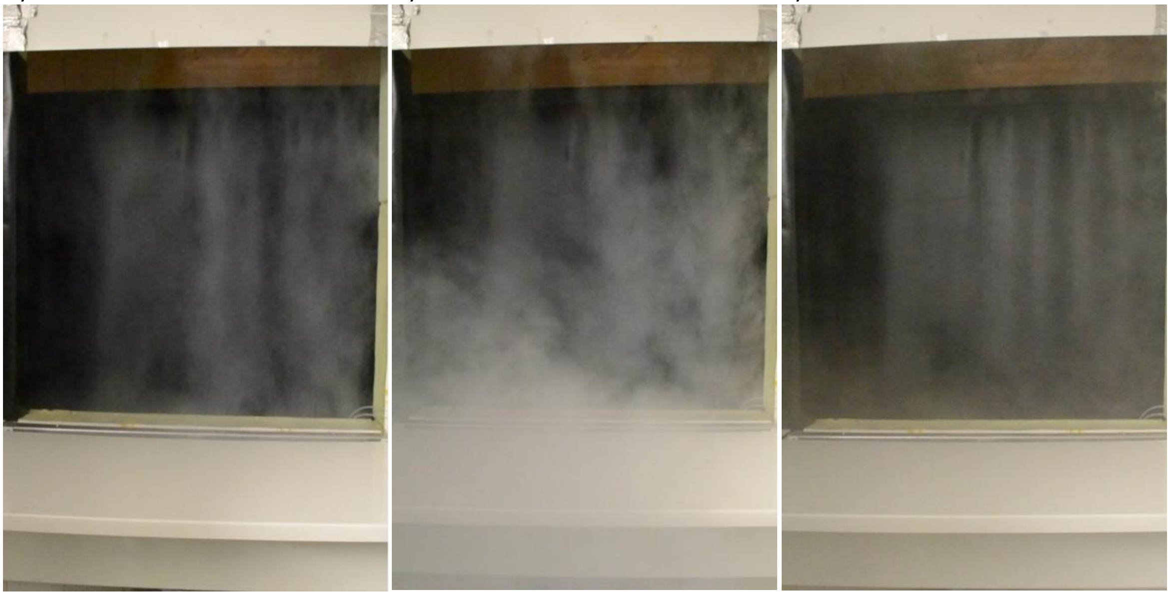


Figure 36. The flow of smoke gas, visualized for case when q_{sup}=173 m^3/h q_{exh}=310 m^3/h effective area =0.04 m^2
a) beginning of smoke test b) center of smoke test c) end of smoke test

As can be see, together with decreasing the internal velocity of slot jet, change the dimensions of jet and also the contents of smoke is higher. May try to formulate, that if the internal velocity is lower, the supply air flows slower than the supply air easier mixed with ambient air. If the internal velocity increases , the momentum of jet is bigger than the jet begins to mix a slightly later. As can be noticed, with the lower internal velocity such as 2.47 m/s or 3.67 m/s the thick layer of smoke concentrates already in the upper parts of jet. In cases where the internal velocity is increased, the smoke begins to swell and spreads in the test room at lower part of jet. Therefore this process may affect to size of jet , with the lower velocity the smoke spreads in upper parts and then the range of angle is bigger. Despite this, the results of smoke test for this series are rather similar. As can be see, the smokiness during and after visualization is very high. Moreover, after the operation the smoke concentration kept for a long time in internal space.

For the reason that the above presented smoke visualization does not satisfy the expected results, carried out smoke test for increased indoor airflow patterns. It was increased range of exhaust air to 660 m^3/h and the dimensions of outlet opening to 0.08m x 1.00m.

Figure 37 shows the profile of jets for changed air parameters.

a) b) c) d)

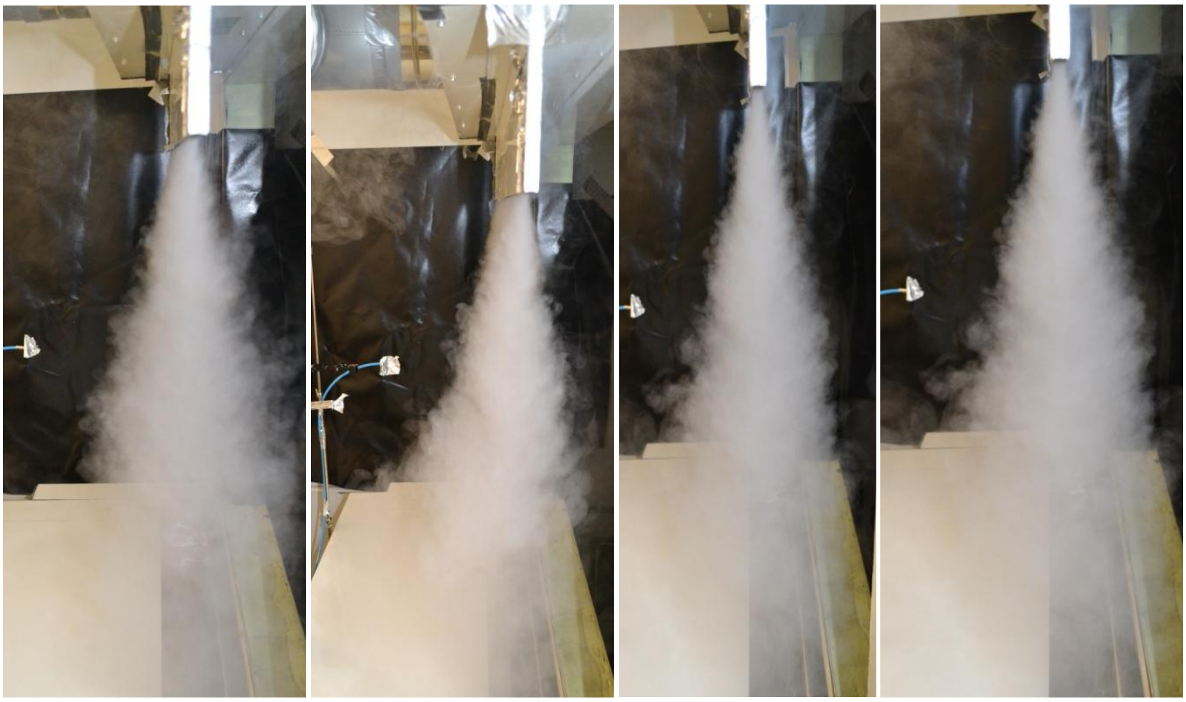


Figure 37. The profile downward plane jet from the air curtain, visualized for case when q_{exh}=660 m^3/h effective area =0.08 m^2 and a) the supply airflow velocity was 2.47 m/s b) the supply airflow velocity was 3.67 m/s c) the supply airflow velocity was 4.57 m/s d) the supply airflow velocity was 5.2 m/s

The shapes of jet looks like very closely, each of them is symmetric jet. The angles of plane jet have relatively similar values namely for a higher internal velocity (as 4.57 m/s and 5.20 m/s) is equal to about 28°, for a lower internal velocity (as 2.47 m/s and 3.67 m/s) is in sequence equal to 24° and 23°. Figure 38, Figure 39, Figure 40 and Figure 41 shows the distribution of smoke in front of to the air curtain.

a) b) c)

Figure 38. The flow of smoke gas, visualized for case when q_{sup}=78 m^3/h q_{exh}=660 m^3/h effective area =0.08 m^2
a) beginning of smoke test b) center of smoke test c) end of smoke test

a) b) c)

Figure 39. The flow of smoke gas, visualized for case when q_{sup}=117 m^3/h q_{exh}=660 m^3/h effective area =0.08 m^2
a) beginning of smoke test b) center of smoke test c) end of smoke test

a) b) c)

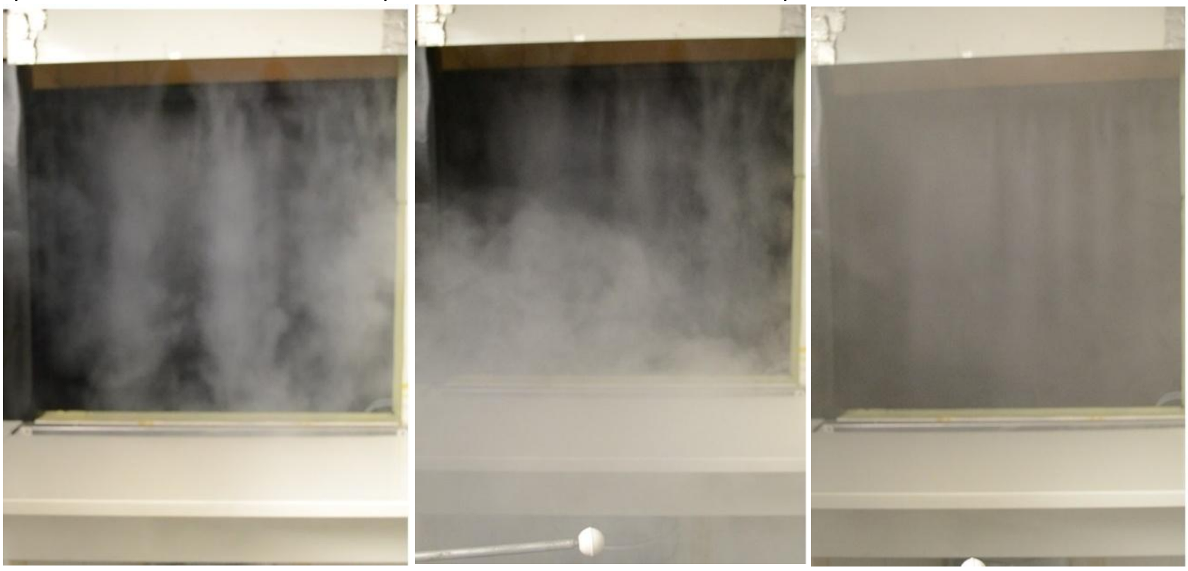


Figure 40. The flow of smoke gas, visualized for case when q_{sup}=147 m^3/h q_{exh}=660 m^3/h effective area =0.08 m^2
a) beginning of smoke test b) center of smoke test c) end of smoke test

a) b) c)

Figure 41. The flow of smoke gas, visualized for case when q_{sup}=173 m^3/h q_{exh}=660 m^3/h effective area =0.08 m^2 a) beginning of smoke test b) center of smoke test c) end of smoke test

Compared these smoke visualizations with the previous tests, it can be observed that the level of smokiness in these series decreased slightly. Some quantities of smoke was immediately removed by exhaust system. The effectives of exhaust air system increase slightly. With the change of volume the exhaust air, increases the turbulences of airflow. The distributed smoke mixed quicker with a ambient air and less whirls and swirls. Also in these series can be seen, the relation between internal velocity and process of mixing the plane jet with indoor air. As shown Figure 38 section *b* the supply air flows with internal velocity begins to mix with ambient air over the entire height of plane jet. In contract , in Figure 41 in section *b* the impulse of downward jet is higher, therefore the supply smoke with higher velocity flows vertically and in lower part of jet mix with indoor air. Sum up the the results of these series, nevertheless, the smoke gas spreads inside in space of test room and the concentration of smoke is still very high.

Due to fact, that the smoke visualization were still unsatisfactory, the visualization conditions were increased again.

Figure 42 shows the forms of plane jet in for four various internal velocity, namely section a – 2.47 , section b –3.67 , section c – 4.57 , section d –5.20.

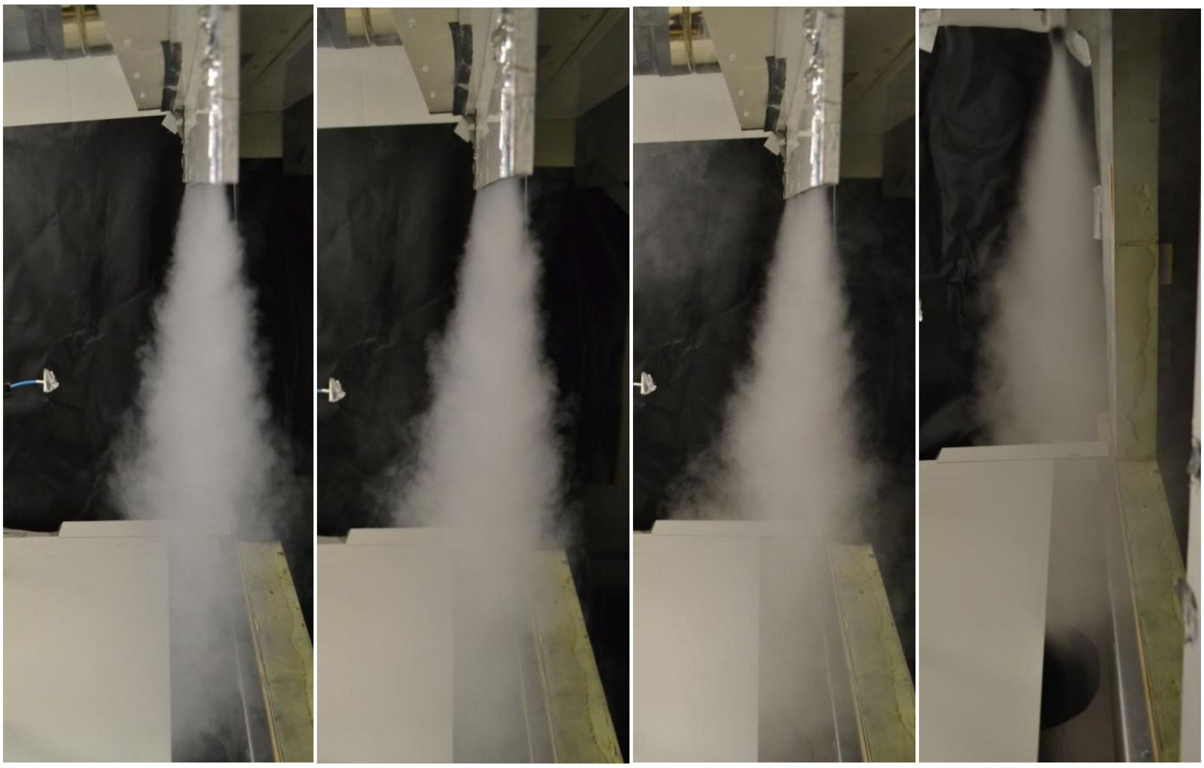


Figure 42. The profile downward plane jet from the air curtain, visualized for case when q_{exh}=1065 m^3/h effective area =0.13 m^2 and a) the supply airflow velocity was 2.47 m/s b) the supply airflow velocity was 3.67 m/s c) the supply airflow velocity was 4.57 m/s d) the supply airflow velocity was 5.2 m/s

The volume of exhaust air and the size of outlet opening are the same for each case in this series. The exhaust of airflow rate is equal to 1065 m^3/h and the outlet air nozzle has dimensions of 0.13m x 1.00m. The profiles of jet are similar for each case. The jets have a symmetric shape and the distribution of smoke is regular . The range of widening angle keeps between 22° (for q_{sup}=173 m^3/h and q_{exh}= 1065 m^3/h) to 28° (for q_{sup}=78 m^3/h and q_{exh}= 1065 m^3/h). For other conditions such as q_{sup}=117 m^3/h and q_{exh}= 1065 m^3/h the angle of jet is equal 26° and for q_{sup}=147 m^3/h and q_{exh}= 1065 m^3/h is equal to 25°.

a) **b)** **c)**

Figure 43. The flow of smoke gas, visualized for case when q_{sup}=78 m^3/h q_{exh}=1065 m^3/h effective area =0.13 m^2 a) beginning of smoke test b) center of smoke test c) end of smoke test

a) b) c)

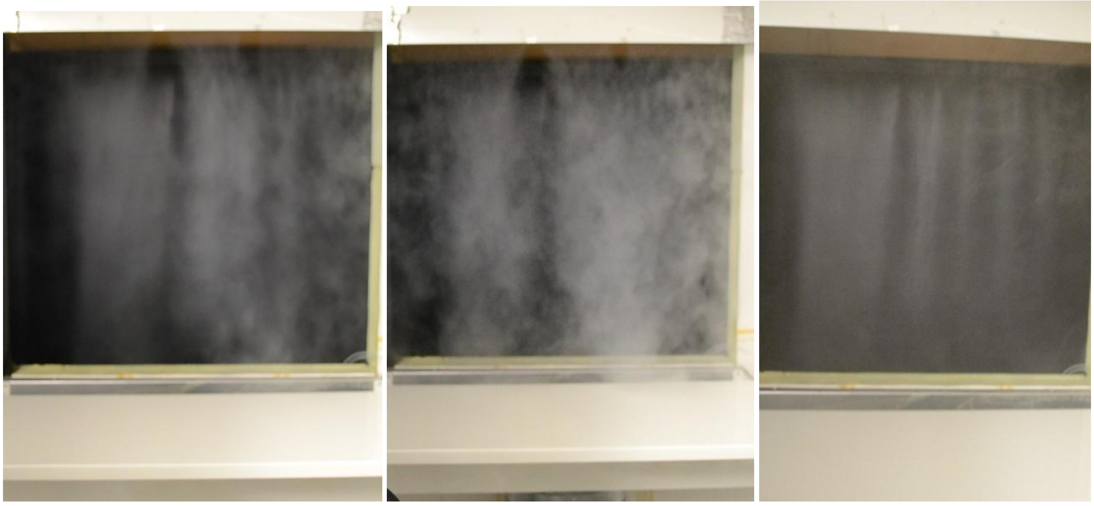


Figure 44. The flow of smoke gas, visualized for case when q_{sup}=117 m^3/h q_{exh}=1065 m^3/h effective area =0.13 m^2
a) beginning of smoke test b) center of smoke test c) end of smoke test

a) b) c)

Figure 45. The flow of smoke gas, visualized for case when q_{sup}=147 m^3/h q_{exh}=1065 m^3/h effective area =0.13 m^2
a) beginning of smoke test b) center of smoke test c) end of smoke test

a) b) c)

Figure 46. The flow of smoke gas, visualized for case when q_{sup}=173 m^3/h q_{exh}=1065 m^3/h effective area =0.13 m^2
a) beginning of smoke test b) center of smoke test c) end of smoke test

A vertical flow of air illustrates also Figure 44, Figure 45, Figure 46. In these series the process of airflow is close to the expected procedure. The transmission of smoke has been reduced. The supply air flows vertically and in lower part of jet does not spread to the sides. The smoke gas is almost removed by exhaust air system and the jet forms kind of ''air wall''. During the observation of test, if marginal quantities of smoke gas remind in test room, the exhaust system quickly removes this kind of contaminations. Theses series is consider as the most effective performance. From among these series the most approved case is a test with internal velocity 2.47 m/s. The selection depends on values of supply and exhaust air parameters. As has been repeatedly mentioned, with the decreasing internal velocity reduces the risk of draft.

Summing, to find the proper and effective procedure of airflow distribution of the downward plane jet, the volume of exhaust air had to be increased up to 1065m^3/h and the effectiveness area of outlet opening up to 0.13 m^2 (0.13 m x 1.00 m). Thought that the volumes of exhaust were various, the shape of jet are rather close to each other. The major difference between cases or series resulted from the concentration of smokiness in the test room and also were depended the effective of remove the smoke gas. The contour of jet resembles the shape of the deltoid (see Figure 47). Near to slot of air curtain, the plane jets have a very narrow shape. With increasing distance from slot the jet stream progressively increases its width. In about three quarters of the height jet, the downward jet reaches the maximum width, then the width begins to decrease. The plane jets may be classified to axisymmetric jet.

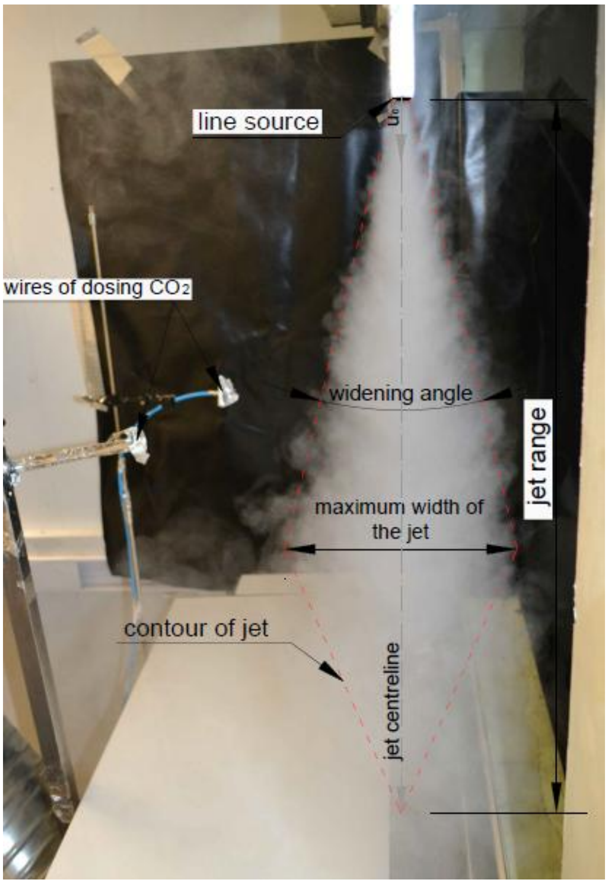


Figure 47. The downward plane jet with characteristic parameters

In order to complete review of distribution the downward plane jet and also to study the possibilities the plane jet to separate a protected zone from target zone, carried out additional smoke visualization. In this case smoke gas will be dosing in polluted zone. The small generated device shows in Figure 48. Device to generate the smoke gas was set at height 1.6 in place of the one the CO_2 dosing wire.

Figure 48. Device to generate the smoke gas

In this way could be simulate the reside of patient in reception space and the breathing functions this person. The smoke gas was supply perpendicularly to plane jet. Thus, this test shows that the plane jet is able to prevent of penetration the gasous or particular aerosols pollutants to protected zone. The conditions of smoke visualization shows Table 82 .

Table 82. Condition of the smoke visualization

Conditions	Values of air parameters
internal velocity [m/s]	2.47
q_{sup} [m^3/h]	78
q_{exh} [m^3/h]	310
dimensions of outlet opening [m x m]	0.04 x 1.00

Figure 49 shows the result of visualization the smoke gas. Performed test shows that dosing smoke forms a jet which is induced by the downward plane jet. At the time of contact the supply air and smoke gas, the gas is absorbed by a plane jet and remove by exhaust system. As can be seen, to protected zone not penetrate the indoor pollutions. The supply plane jet forms kind of ''air wall'' which effective divide open space into two zone with the difference conditions. Moreover it can be observed, when perpendicular supplied smoke jet approaches to plane jet , the smoke is directed toward to slot of air curtain. This process may provide that the highest volume of ambient air is induced in first part of jet, near the slot. During this test could be image two standing people in two different zones opposite each other. One of them is sick person who coughs, sneezes and together with exhaled air spreads the bacteria and virus of infectious diseases. By using the downward plane jet the exposure of person inside the protect zone such as nurse is reduce. The polluted air is stopped by supply plane jet.

Figure 49. Smoke visualization with dosed gas in contaminated zone

5.3. Examine the airflow distribution of the downward plane jet

Examine of the airflow distribution of plane jet consists the experimental measurement of velocity across jet. Having regard to previous measurement results and emerging conclusions relating to propose the effective procedure for experimental space, the measurements of velocity distribution were carried out in three difference cases. During the selection of a measurement conditions focusing on the air parameters which were the most appropriate in a previous measurement.

In first case, measurement was conducted without using the local exhaust. This case shows the velocity decay for the supply airflow rate is equal to 78m^3/h. Table 83. The results of measurement the velocity across a plane jet – case no. 1shows the values obtained for case no. 1.

Table 83. The results of measurement the velocity across a plane jet – case no. 1

		Case 1: qsup=78 m3/h qexh= 0 m3/h								
		horizontal distances from the air curtain								
vertical distance from curtains		x4 0.18	x3 0.13	x2 0.08	x1 0.03	x 0	-x1 0.03	-x2 0.08	-x3 0.13	-x4 0.18
h	0	0.02	0.014	0.018	0.072	**2.613**	0.022	0.044	0.023	0.018
h1	0.22	0.085	0.086	0.104	0.664	**1.091**	0.205	0.092	0.088	0.087
h2	0.44	0.052	0.068	0.24	0.625	**0.714**	0.362	0.248	0.188	0.115
h3	0.66	0.117	0.222	0.308	0.485	**0.529**	0.366	0.322	0.205	0.141
h4	0.88	0.277	0.305	0.258	0.259	0.242	0.270	**0.288**	0.27	0.211

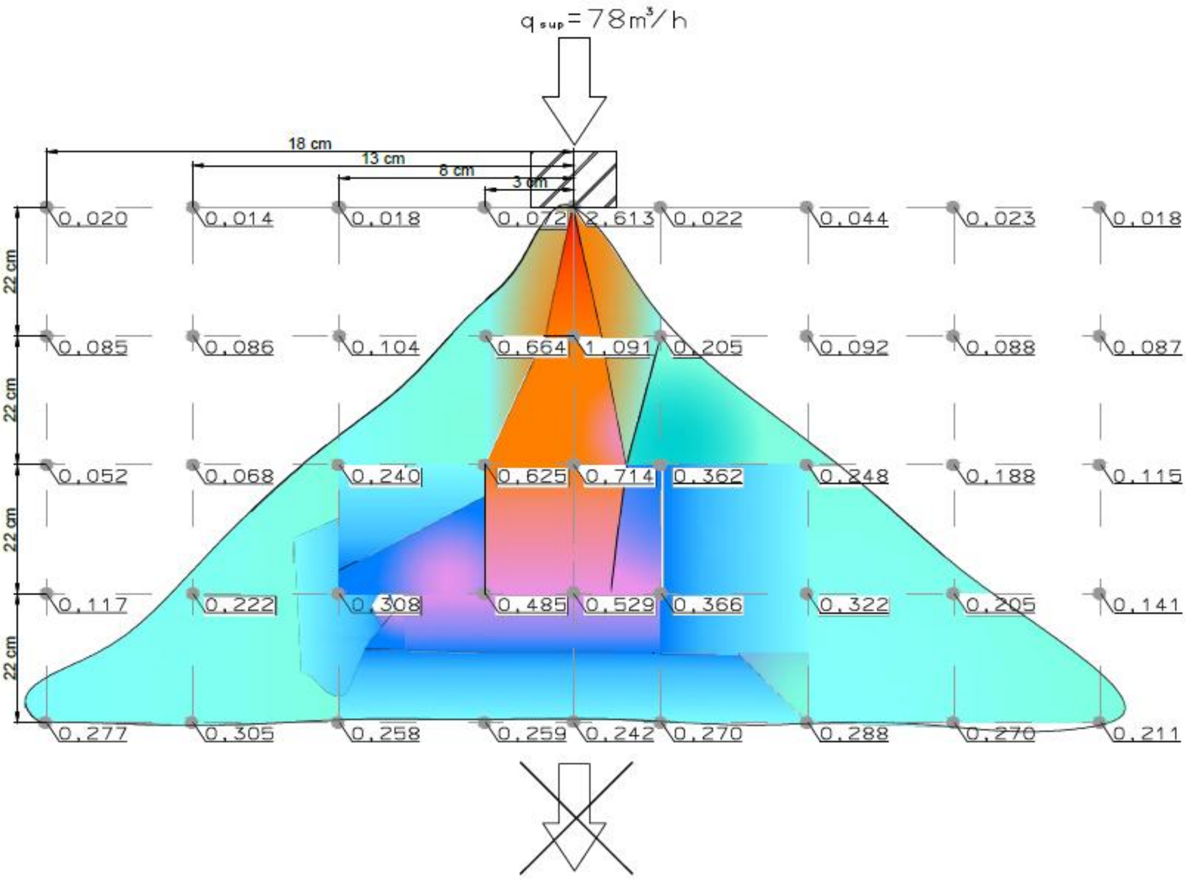


Figure 50. Illustration of velocity distribution across a jet for q_{sup} equal to 78 m^3/h without using the exhaust air system

The internal value of velocity is equal to 2,61 m/s. In first part, namely at distance h_1=22 cm the jet is highly concentrated. In this part the jet induces the greatest amount of ambient air. With inductions of jet changes the volume of jet increases and also the shape of jet. The beginning of transformation of shape is visible at the distanceh_1=22cm. The width of the jet increases. In this distribution of downward plane jet the highest velocity are kept in centerline jet. The values of this velocity decrease with the increasing distance. The value is decreased up to decay of velocity. Approximately, the process of decay of the centerline velocity can be seen at the distance h_3=66 cm from an air curtain, in centerline jet. In this point the velocity is equal 0.53 m/s while at increased distance to 88cm the value of velocity falls to 0.24m/s. At distance between 66 cm and 88 cm was drastic decrease of velocity. It can be state, that the velocity distribution across the jet is correct and compatible with theoretical divagations. In this case the airflow is almost stabilized, any turbulence may be related to mixing of a supply air with an ambient air. The values of results pointed that it is a axisymmetric jet, namely the values at the same vertical distance from curtains (h_x) and at horizontal distances from the air curtain on different sides of jet are very close.

With reference to the measurement of CO_2 concentration, the second case was carried out with supply airflow rate 78 m^3/h and exhaust airflow rate 310 m^3/h. The measurement results are summarized in Table 84.

Table 84. The results of measurement the velocity across a plane jet – case no. 2

Case 2: qsup=78 m3/h qexh= 310 m3/h

			horizontal distances from the air curtain								
			x4 0.18	x3 0.13	x2 0.08	x1 0.03	x 0	-x1 0.03	-x2 0.08	-x3 0.13	-x4 0.18
vertical distance from curtains	h	0	0.004	0.005	0.023	0.014	**2.372**	0.065	0.064	0.028	0.017
	h1	0.22	0.084	0.089	0.101	0.403	**0.977**	0.297	0.094	0.085	0.076
	h2	0.44	0.042	0.156	0.172	0.507	**0.679**	0.438	0.253	0.172	0.176
	h3	0.66	0.082	0.163	0.306	0.457	**0.540**	0.395	0.325	0.199	0.142
	h4	0.88	0.176	0.243	0.266	0.345	**0.477**	0.408	0.386	0.183	0.194

Figure 51 illustrates the velocity distribution across the jet.

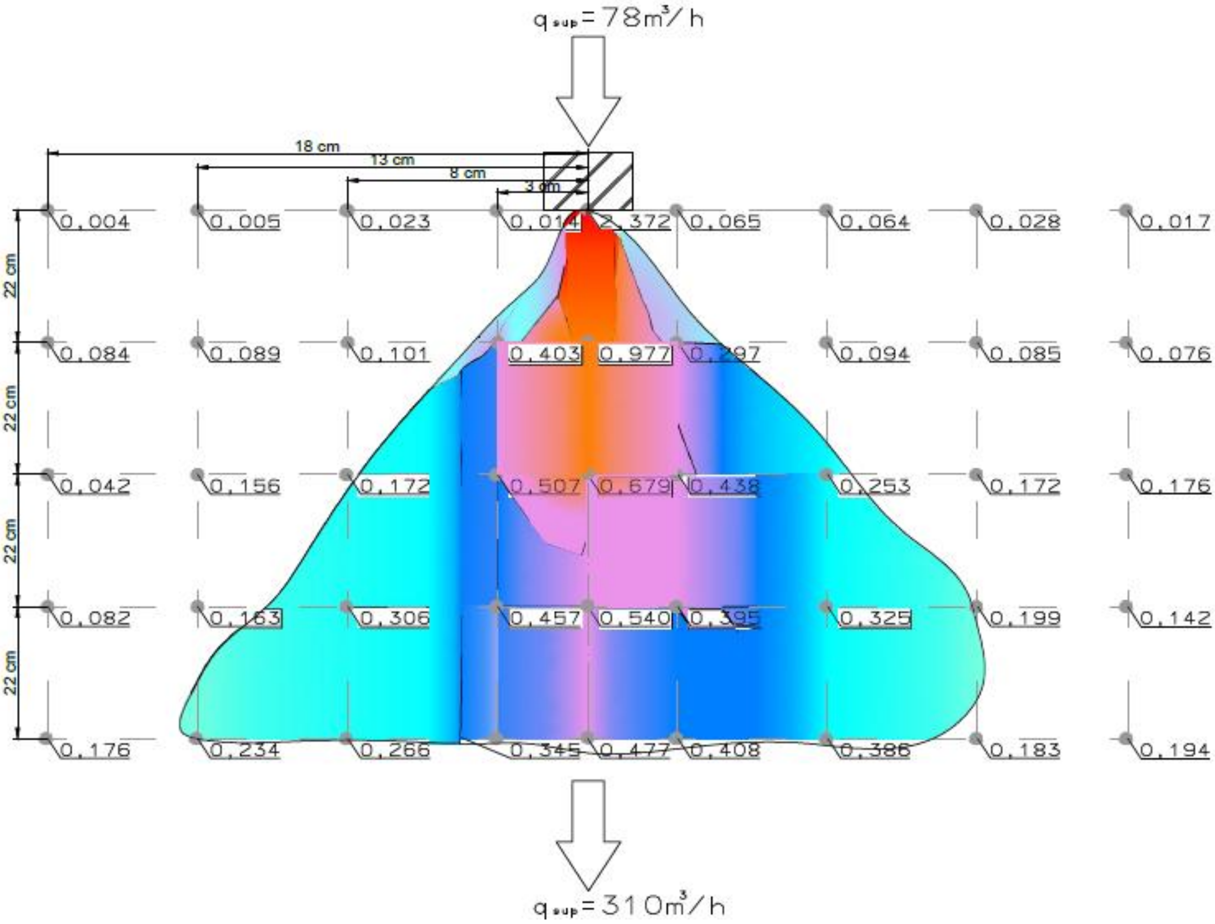


Figure 51. Illustration of velocity distribution across a jet for q_{sup} equal to 78 m^3/h, q_{exh} equal to 310 m^3/h and effective area of outlet opening 0.04 m^2 (0.04m x 1.0m)

As can be see, the highest velocity is kept close to the slot of air curtain. The maximum value of velocity is equal to 2.37 m/s. This velocity is identified as internal velocity. With increases vertical distance from the slot jet, the air velocity decreases. Decrease of velocity entails a decrease of air volume flow. The maximum air velocity for each vertical distance such as h_1,h_2,h_3,h_4 always presents along the centerline jet. Analyzing the results, as can be seen, that the maximum width of jet is at vertical distance 0.66 m from the slot of air curtain. The half of maximum width ($x_{max)}$) is on the edge

0.08 m. However, it can be seen influence of the operation exhaust air system. In contract to previously case the centerline velocity decayed at 0.66 m from the slot of air curtain, in this case the velocity consistently decreases but still has a high value. The exhaust system supports the flow jet, suction jet in the direction of outlet opening. The values of velocity in a center part of jet (at distance 3 cm from the axis for both of side jet) at the level of counter are higher than in case without implementation the local exhaust.

Table 85 shows the results of case no 3. This case was carried out for volume of supply air equal to 78 m^3/h and for volume of exhaust air equal to 1065 m^3/h. These conditions were the most suitable during the smoke visualization.

Table 85. The results of measurement the velocity across a plane jet – case no. 3

Case 3: qsup=78 m3/h qexh=1060 m3/h

			horizontal distances from the air curtain								
			x4 0.18	x3 0.13	x2 0.08	x1 0.03	x 0	-x1 0.03	-x2 0.08	-x3 0.13	-x4 0.18
vertical distance from curtains	h	0	0.008	0.004	0.015	0.012	**2.305**	0.08	0.089	0.08	0.067
	h1	0.22	0.115	0.097	0.136	0.791	**1.082**	0.234	0.145	0.126	0.126
	h2	0.44	0.111	0.131	0.304	**0.686**	0.585	0.292	0.264	0.162	0.163
	h3	0.66	0.231	0.31	0.45	**0.561**	0.47	0.375	0.322	0.264	0.186
	h4	0.88	0.279	0.449	0.967	**1.895**	1.805	1.841	0.767	0.31	0.241

In case no. 3 the centerline of the downward plane jet is a bit curved, namely the axis of jet is slightly offset into the polluted zone. This effect may be due to the intense operation of the exhaust system. As known, the outlet nozzle is placed in contaminated zone. The significant exhaust airflow rate causes that trajectory of supply plane jet is determined by exhaust ventilation system.

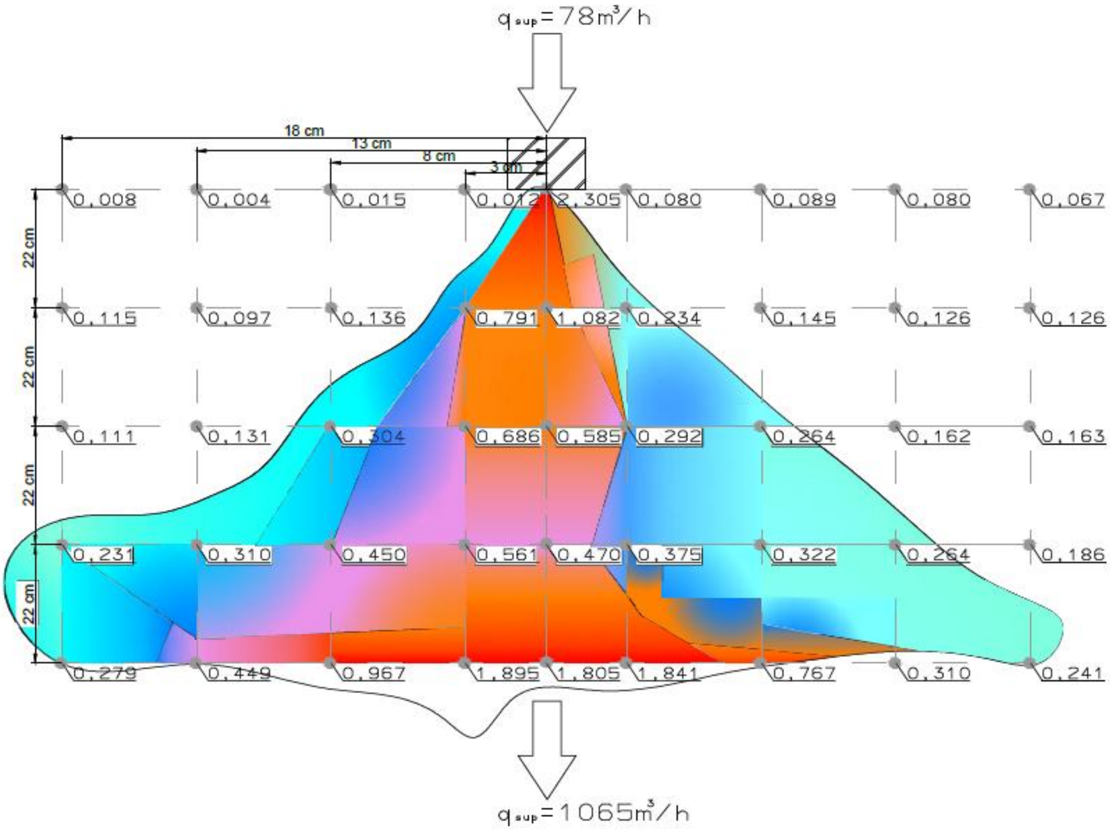


Figure 52. Illustration of velocity distribution across a jet for q_{sup} equal to 78 m^3/h, q_{exh} equal to 1065 m^3/h and effective area of outlet opening 0.13 m^2 (0.13m x 1.0m)

As shows Figure 52 the internal velocity decreases form 2.31 m/s to 0.56 m/s at the distance from slot 0.66 m and than begins to increase up 1.90 m/s. The velocity 1.90 m/s is reached in the lowest part of downward jet, near to center of exhaust nozzle. The high values of velocity are kept both close to slot of air curtain and at the level of corner with outlet opening. In this case can be observed a high impact the operation of the exhaust system. In compare to previously cases, the flow of jet is more turbulence. For the tempestuous flow affects not only mixing a supply air with an ambient air but also the high exhaust airflow rate which intensively mixed the air. At vertical distance 0.66 m the plane jet is assumed by the exhaust system.

Compare the experimental measurement of velocity across jet, the velocity distributions between slot of air curtain and the distance h_3=0.66m are similar, as show Table 86. For example, in table listed the maximum values of velocity along the distance to 0.66.

Table 86. Compare the values of maximum velocity across jets at difference heights under various conditions

Vertical distance [m]	Maximum velocity [m/s]		
	case I	case II	case III
h_0=0 m at the slot	2.61	2.38	2.31
h_1=0.22 m	1.09	0.98	1.08
h_2=0.44 m	0.75	0.68	0.69
h_3=0.66 m	0,. 3	0.54	0.56

However the major difference of velocity distribution can be seen, in the lowest part of jet. Depending on the volume of exhaust air system, variously formed the distribution of the downward jet. With the increase the exhaust, increase the velocity at level of counter.

Furthermore, the experimental measurement results was used to the calculation of factor K, namely the momentum profile coefficient. K is the dimensionless constant of the jet. The values factor depends on the effectiveness area of supply device and also the shape of this device. The recommended values for line source such as air curtain by Rajaratnam (1976) is equal to 2.47 m/s. This value was also used in similar experimental study with using the air curtain (Chen and Rodi, 1980; Kulmala et al., 2007 ; G. Cao, 2015). Table 87 summary the conditions necessary to calculate the
factor K.

Table 87. The result of calculation the factor K

No.	Case	Umax	Ux	b	H	k	$k_{average}$
		m/s	m/s	m	M		
1	Case1	**1.091**	**2.613**	0.009	0.22	2.064	2.435
2		**0.714**			0.44	1.911	
3		**0.529**			0.66	1.734	
4		**0.242**			0.88	0.916	
5	Case2	**0.977**	**2.372**		0.22	2.036	
6		**0.679**			0.44	2.002	
7		**0.54**			0.66	1.950	
8		**0.477**			0.88	1.988	
9	Case3	**1.082**	**2.305**		0.22	2.321	
10		**0.686**			0.44	2.081	
11		**0.561**			0.66	2.084	
12		**1.895**			0.88	8.129	

The reached values of the factor K is equal to 2.435. These values is very close to theoretical assumptions.

6. Future work

The most problematic issue may seem the execution of outlet opening, namely sizeable area of nozzle and also localization of outlet near the occupants. In order to sit of outlet opening with furniture in reception space recommended to performance the opening from perforated sheet. The small holes will be enable to flow of air while the exhaust opening will be camouflaged. The system was performed of elements with large cross sections as well as generated noise. However, this system has been made from the simplest and the most necessary elements and were not installed additional device for reducing the amount of noise emitted by supply and exhaust air system. Furthermore, increased number of change the direction of airflow due to limited space also contributed to the formation of noise. Therefore, before the implementation of this technique, it must still be improved. As known, this experimental study is a first part of the research on protect zone ventilation and should be continue. Certainly, idea using the air curtain to separate two zones and a reduction of transmission indoor pollutions from target zone to protected zone, may be successful and efficient solution.

7. Conclusion

Developed procedure for reception space using protected zone ventilation is able to separate the open space into two zones with different concentration levels of contaminant. During the experimental study, detailed two types of experimental methods, measuring CO2 concentration and visualization, were conducted to investigate the performance of downward plane jet regarding prevention of transmission of pollutants from one zone to another.

Firstly, focus was put on the measurement of CO_2 concentration with difference airflow patterns. As demonstrated, the most effective volume of supply air is equal to 78 m^3/h and exhaust volume of air is equal to 310 m^3/h. This values of airflow prevents the transmission of indoor pollutions and kept the concentration of CO_2 at level less than 500 ppm. The measurement of velocity distribution shows that internal velocity of jet 2.47 m/s should not contribute to local drafts. As can be seen, for the most effective parameters (q_{sup}= 78 m^3/h, q_{exh}=310 m^3/h), in place where probably will stand one sick person, namely at the horizontal distance about 18 cm from the centerline jet and at various height from 1.1m to 2.0m, the values of velocity are kept at a lower level. The velocity on the edge of jet is almost equal to the velocity of ambient air. The similar distribution of velocity is on the other side of the jet. The exposure of nurses and other healthcare workers to draft should be minimized. Under this conditions the thermal comfort and suitable quality of air shall be maintained. In addition, the high efficiency of the system was reached. Almost 80% indoor pollutions does not enter the protected zone.

However, other obtained results should not be ignored. It should be noted that in this study the tracer gas CO_2 was used to simulate the indoor pollutions. Moreover, it was assumed that CO_2 with a concentration of 500 ppm will not be hazard to surrounding people. In other conditions or applications of the air curtain, the results may reach entirely different values. For each case or more specifically for each type of hazardous contamination, the possibilities of using a downward plane jet to prevent the protected zone should be verified.

The second type of measurement concerned on visualization the airflow distribution. During the test, the smoke was dosed in the contamination zone. Meanwhile, the supply airflow rate was $78m^3/h$ and exhaust airflow was $310m^3/h$. The plane jet blocked the smoke from transferring from one zone to the other. The contamination was mixed with a plane jet and then was removed by the exhaust system. However, during the visualization it was found that the smoke was entrained o the supply air system, and the supply downward jet mixed with ambient air and pollutant was spread to both zones. This study found that it might be a risk that the air flow will support the transmission of bacteria or viruses through different zones. Increasing the volume of exhaust air to $1065m^3/h$ and the effective area of exhaust opening from 0.04 m^2 to 0.13 m^2 caused that the downward plane jet with and taken over pollution was almost removed by exhaust system.

The results of this study indicate that the protected zone ventilation with a downward plane jet may be able to lower significantly personal exposure to the other person's exhaled airflow even when two persons are standing close to each other. Many factors influence the possibilities of using a downward plane jet to reduce the exposure of surrounding people to from both gaseous and particulate pollutants. However, the behavior of occupants may also affect the performance of the operation of downward plane jet, for example, opening the door or changing postures in the office. At the same time, it should be remembered that improperly designed ventilation systems and their improperly implementation may be the driving force of transmission of bacteria and other pollutions. This study may be helpful to analysis the performance of the protected zone ventilation and the operation of this type of ventilation system. The future experimental work should be conducted to develop the PZV further and to increase its effectiveness.

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