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ANALYSIS OF CO_2 CONCENTRATION DISTRIBUTION INSIDE AND OUTSIDE SMALL BOILER PLANTS

ANALIZA ROZKŁADU STĘŻEŃ CO_2 WEWNĄTRZ I NA ZEWNĄTRZ BUDYNKU NIEWIELKIEJ KOTŁOWNI

Abstract: Analysis of the distribution of CO_2 concentrations was performed for a water-and-steam boiler plant located in a detached building supplying thermal energy to a hospital. The boiler plant was equipped with two low-temperature boilers and one high-temperature steam boiler. The maximum thermal energy demand of the hospital was 4280, 3500 kW of which came from the hot-water boilers and the remaining 780 kW from the steam boiler. Due to the operating system there were no permanent job positions in the boiler plant. Servicing consisted only in the supervision, periodic adjustment and maintenance of the equipment. These kinds of working conditions release the employer from the necessity to perform tests and measurements of working conditions in such a building. On the other hand, continuous measurements are made because of the installation safety and emissions of pollutants into the environment. The article presents results of the measurements and analysis of the distribution of CO_2 concentrations inside and outside a small boiler plant, due to which it was found that the level of carbon dioxide concentration did not depend on the ambient air temperature. The resulting values are similar regardless of whether the measurements were taken in December 2012 or April 2013. However, there is an evident impact of seasons on the concentrations in the indoor air associated primarily with the demand for heat during the given period, the stay of people in the workplace and the number of working devices.

Keywords: combustion, CO_2 emissions, working conditions, immission

Introduction

Air pollutants are all solid, liquid or gas substances whose share in the air exceeds the average quantity of these substances in clean air. These are the components which are emitted to the atmosphere both in a natural way and as a result of human activity. It is not easy to determine the impact of individual pollutants on human organism and/or natural environment. For this reason a monitoring and air protection system is necessary. In Poland such a system is controlled by regional air quality assessment systems supervised by the Regional Inspectorates for Environmental Protection.

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Boiler house is a building in which there may be a risk of emissions of substances harmful to human health. Therefore, care should be taken of the working environment providing comfortable conditions related to humidity, cleanliness, temperature and appropriate amount of solid and gas substances. One of the most important parameters is the multiplicity of air exchange which results from the use of the room and should ensure such air exchange so as not to exceed the highest acceptable concentrations of substances polluting the indoor air [1].

The main source of pollution in close rooms is carbon dioxide whose level so far has not been taken into account while designing ventilation systems. However, for some time a significant change has been observed because in ventilation systems automatic control of air flow depending on carbon dioxide concentration in a room is used increasingly thus ensuring appropriate comfort for people staying in a given building [2-4].

According to Polish regulations ventilation should meet the following requirements [5]:

- supply an appropriate amount of air,
- dissolve and remove noxious gases emitted in boiler plants,
- not allow a concentration increase above the flammability or explosion limit in the case of gas release from the installation,
- maintain appropriate air parameters in the boiler plant so as not to endanger the boiler operator.

The control of CO_2 concentration by means of its active removal can provide many benefits such as helping to achieve the objectives of ‘carbon neutrality’, as well as improving air quality in rooms by decreasing exposure of users of the building to CO_2 [6].

It should be noted, however, that in people CO_2 at low concentrations is a normal component of blood gas and only in the case of high exposure this is a gas which can cause fatal effects. It is one of the strongest known stimuli that could affect breathing, which means that people are very sensitive to changes in the concentration of CO_2 in the air. Inhalation of elevated CO_2 concentrations can increase blood acidity, with negative impacts for both respiratory and cardiovascular or central nervous system [7, 8].

However, as regards the external air quality the Polish Environmental Protection Law [9] does not define carbon dioxide as a substance adversely affecting the environment. The level of CO_2 in the atmospheric air is not defined as acceptable, it is not monitored by the State Environmental Monitoring (monitoring of emissions of this gas is carried out solely for the purpose of emissions trading).

The sources of external air pollutant emissions are primarily local (central and local) and district heating systems which provide thermal energy for both housing and industrial facilities and services resulting in the formation of harmful substances in the atmospheric air [10-15].

Work environment in a small boiler plant

Systems of work in small boiler plants are characterized by the fact that there are no permanent job positions, that is where the work is performed for more than four hours, more than 4 times per hour during one shift. Then, in Poland, their lack releases the employer from having to perform tests and measurements of the work environment. On the other hand, in accordance with the Regulation of the Minister of Health on tests and measurements of harmful factors in the work environment, based on knowledge of the type of work, work organization and processes the employer may determine the type and scope of tests and measurements performed in the work environment [1]. However, taking into account the very short stay of workers in such places (only for maintenance and supervision of equipment) it is not necessary to examine factors of occupational hazards. On the other hand, continuous measurements are made in respect of the installation safety and pollutants emitted into the environment. If in the boiler house there are gas boilers then there are also gas and carbon monoxide detectors installed (one over each boiler) to carry out continuous monitoring.

In the work environment in the boiler plant there are the following harmful and dangerous substances to which workers are exposed during maintenance, control and supervision:

- carbon monoxide (CO), whose maximum permissible limit (MPL) at workplaces (8-hour exposure) is equal to 23 mg/m^3, while the maximum permissible short-term limit (MPSTL), *ie* the highest permissible instantaneous concentration is 117 mg/m^3 [1];
- sulfur dioxide (SO_2) with MPL equal to 1.3 mg/m^3, and MPSTL equal to 2.7 mg/m^3 [1];
- carbon and ash dust generated during carburizing, combustion and deslagging;
- noise, *ie* all unwanted, annoying, unpleasant, nuisance or harmful sounds acting on the organ of hearing, as well as other senses of an employee, the maximum noise in relation to the 8 hour working day is 85 dB, whereas the maximum sound level 115 dB and a peak sound level 135 dB [1];
- microclimate caused by elevated temperature and low humidity.

During operation of every boiler plant important is also the emission of carbon dioxide (CO_2), although most often it is not taken into account as a risk factor in the workplace. Its sources are both natural and anthropogenic. In the case of the work environment only these may be taken into consideration which result from human activities. These include all combustion processes in power generation, industry and transport.

Maximum permissible levels of CO_2 in the workplace are very high reaching 9000 mg/m^3, and the maximum permissible short-term limit being 27000 mg/m^3 [1]. For this reason it is occasionally tested by employers.

To prevent the negative effects of human exposure to all the factors that may arise in the work environment in the boiler plant, it is required to use preventive technical and organizational measures which include:

- meeting the requirements concerning technical conditions for rooms and buildings of boiler plants;
- complying with the requirements of manuals and instructions for operation of the installation;
- admission of people with appropriate permissions and qualifications to work in boiler plants;
- current control of the technical state of boilers and auxiliary equipment;
- conducting timely maintenance and technical inspection.

According to the Regulation of the Minister of Economy on safety and occupational health in work with power equipment in Poland, similar to other countries [1], it is forbidden to:

- use power equipment without protective devices in the meaning of general work safety and occupational health regulations,
- make changes in the applied security measures if this would worsen the level of safety.

Additionally, during boiler operation it is forbidden to:

- start up a boiler with damaged control or safety devices,
- fire up the boiler after finding that there is no chimney draft,
- place beds and sleep in the boiler plant,
- operate the boiler while drunk,
- let in unauthorized persons to the boiler plant,
- leave the boiler plant without notifying the supervisor,
- enter the fuel or slag tanks.

The presence of CO_2 in the work environment at too high concentrations may be linked to 'sick building' syndrome, but it is not a major determinant of the occurrence of such symptoms in workers. The concentration of CO_2 may be directly connected with other pollutants of work environment causing these symptoms [16-20].

Characteristic of the tested area

The analyzed boiler is located in the Hospital of the Military Medical Academy in Lodz, 113 Zeromski St. It is located in a detached building, made of steel, having a gravity ventilation. The building is 7.2 m high, has an area of 202.34 m^2 and cubic capacity of 2598 m^3. In the immediate vicinity there are traffic arteries with significant traffic, and the nearest building is 3.5 m, while the main building in which most people stay is about 120 m from the boiler plant. On the north and south the boiler plant is surrounded by internal communication paths for both car traffic and pedestrians. On the south-west there is a building and on the north-east an open ground under the surface of which there is a gas reducer (from medium to low pressure) and a redundant line through which excess gas from the network escapes into the atmosphere. The result is that from this side the area with a diameter of about 10 meters has to be a zone free from all buildings and not intended for any kind of utilization (Fig. 1).

In the boiler plant there are two low-temperature boilers and one high-temperature steam boiler which provide heat and hot water to all buildings located on the hospital grounds. The maximum demand of the hospital for thermal energy is 4280 kW of which 3500 kW comes from the hot-water boilers, and the remaining 780 kW from the steam boiler. The boiler plant is supplied with natural gas of type E (formerly GZ-50) - the hourly gas consumption being 630.8 Nm^3/h, and EKOTERM fuel oil (in normal conditions the oil demand is 518 dm^3/h), which is used as a reserve fuel when gas boilers do not cover the total energy demand. Pipes supplying gas to low-temperature water boilers are below the platform and the installation is made of black steel pipes joined by welding. Oil is stored in one-chamber bunded tanks. The installation is constructed from steel pipes.

Heat circulation in the water boilers is controlled automatically, the system reaches a constant set temperature of power supply to the primary circuit by controlling the efficiency of burners. Temperature of the heating medium is adjusted directly in heat substations depending on the outside temperature. Automatic devices installed for water boilers in the technological system enables automatic regulation of the system. Maintenance operations consist of supervision, periodic adjustment and maintenance.

The situation is similar with the steam boiler where the installed automatic devices enable automatic regulation of the system and maintenance work is limited to the supervision and inspection of the system, regular desalination and desilting of the boiler, cleaning gauges of the boiler and supply tank, quality control of water supplied to the boiler, changing of the operating boiler pump once a week, checking the operation of safety devices of the steam boiler, periodic adjustment and maintenance of the equipment.

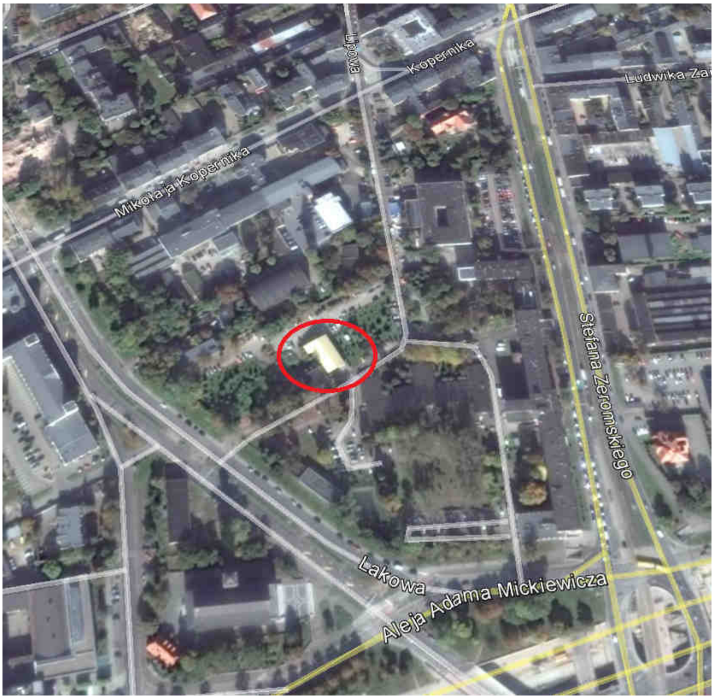

Fig. 1. View of the area in the immediate vicinity of the water-steam boiler plant [21]

Measurement methodology

Concentrations of CO_2 inside and outside the boiler plant were measured using a portable gas microchromatograph (Pollution S.p.A.) (Fig. 2). The device was used to carry out analyses in field conditions, and due to mounting a PPQ column in the measuring apparatus (Table 1) and thermal conductivity detector (TCD) it was possible to analyze samples with minimum concentration of 500 ppb for up to 300 seconds [22].

Table 1

A measurement column of microchromatograph VEGA-GC [22]

Name of column	Description	Exemplary gases
PPQ	Packed column, application: hydrocarbons containing carbon particles from C_1 to C_4	N_2; N_2O; H_2O; CO_2; CH_4; acetylene; ethane; chloroethylene; ethanol; ethylene; propane; hydrogen sulfide and ammonia

Fig. 2. Microchromatograph VEGA-GC [22]

The method developed by Cichowicz to measure carbon dioxide by VEGA-GC microchromatograph was used [4]. During measurements the measuring instrument was set both inside and outside the analyzed boiler room. The measurements were carried out in December 2012 and April 2013 and the selected months were not irrelevant because in winter the boiler supplied central heating and hot water, while in summer hot water only.

Meteorological conditions were determined based on data from the meteorological station (Table 2) located at Wladyslaw Reymont airport in Lodz [23].

Table 2

Weather data [23]

Date of measurement/Parameter	13.12.2012	19.04.2013
Air temperature [°C]	–7	14
Apparent temperature [°C]	–10	12
Wind speed [km/h]	4	3
Pressure [mm Hg]	745	1008
Air humidity [%]	98	85

The level of carbon dioxide inside and outside the hospital boiler plant

During tests carried out in December 2012 in the boiler plant there were 3 people, while in April 2013 there were 4 people. The building was equipped with natural ventilation, and measurements were made at two levels (Fig. 3): 0.00 m (level I) and 3.50 m (level II). The measuring points were located in specific places of the boiler plant (mainly in the area of boilers, valves and controls, and heating system). At level I 32 measurements were performed in 11 points and the microchromatograph was positioned on the floor, *ie* at 0.00 m. At level II 18 measurements were taken in December 2012 and 21 in April 2013 in 6 and 7 points, respectively, located 3.50 m over the boilers.

In December 2012 at the start of measurements in the boiler the concentration of carbon dioxide was 489.442 ppm (948 mg/m^3), and afterwards it was slightly lowered to a level of 447.663 ppm (868 mg/m^3). Carbon dioxide concentration ranged from 400 to 500 ppm (775-969 mg/m^3) (Fig. 4), which is comparable with the data provided in the literature. Very similar concentrations were obtained at level II in December 2012, as they were in the corresponding range of 400 to 500 ppm (775-969 mg/m^3) (Fig. 5). In Figures 4 and 5 the value of the average concentration outside the boiler plant which amounted to

435.735 ppm is indicated in red. On the basis of both Figures it can be concluded that on the measurement day there was no influence of the height and location of the points on CO_2 concentration.

Fig. 3. The interior of the water-steam boiler plant with levels 0.00 m and +3.50 m

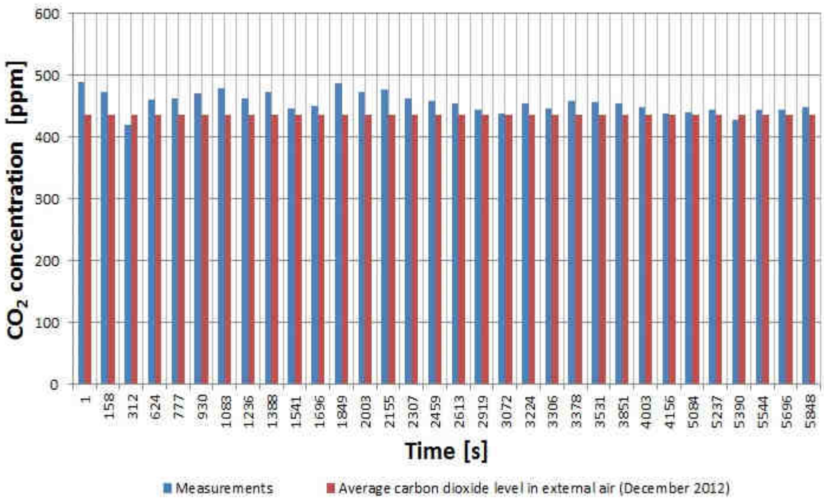

Fig. 4. Change in CO_2 concentration inside the boiler plant (+0.00 m) - December 2012

Subsequent measurements were carried out in April 2013. The measuring device was placed in the same measurement points as in December 2012. In the boiler plant the number of people changed and there was different temperature outside and inside. The concentrations of carbon dioxide at level I ranged from 350 ppm (678 mg/m^3) to 470 ppm (911 mg/m^3) (Fig. 6). However, at level II the CO_2 concentration was in the range of

400-450 ppm (775-872 mg/m^3) (Fig. 7) and the average concentration outside the boiler plant was 388.499 ppm (marked in red in Figs. 6 and 7).

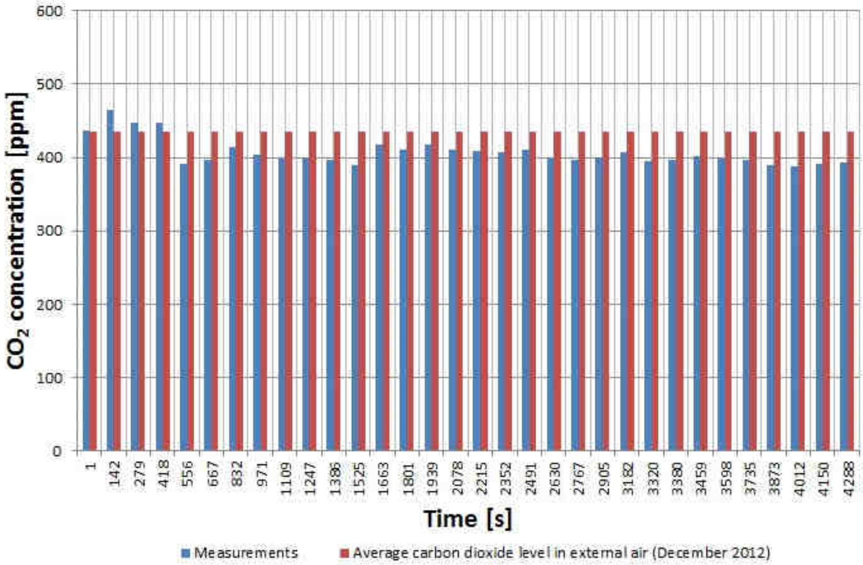

Fig. 5. Change in CO_2 concentration inside the boiler plant (+3.50 m) - December 2012

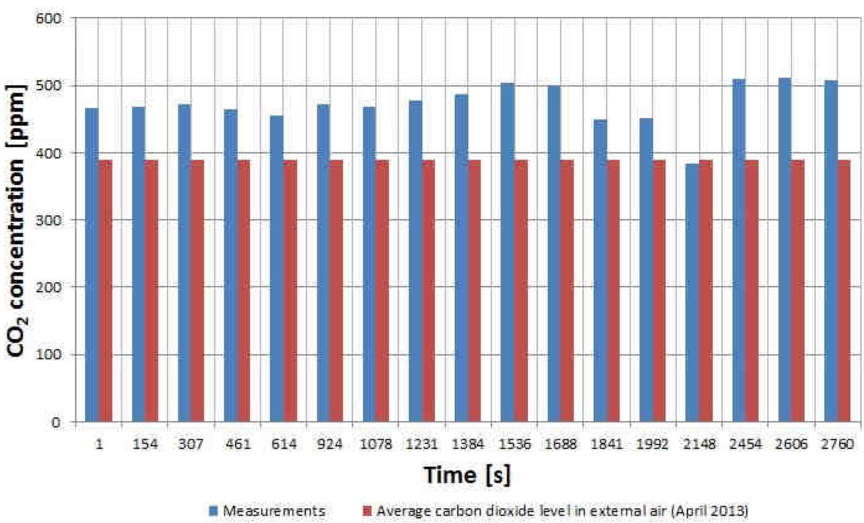

Fig. 6. Change of CO_2 concentration inside the boiler plant (+0.00 m) - April 2013

Subsequent measurement points were located outside the boiler plant in the corners of the building. In December 2012 20 measurements were made and carbon dioxide concentrations ranged from 400 to 500 ppm (775-969 mg/m^3) (Fig. 8), forming a trend line of the equation $y = 1.0511x + 424.7$. In April 2013 only 10 measurements were performed due to unfavorable weather conditions (rain). The CO_2 concentration was in the range of 400 ppm (775 mg/m^3) (Fig. 9), and the equation of the trend line was $y = 0.439x + 386.08$.

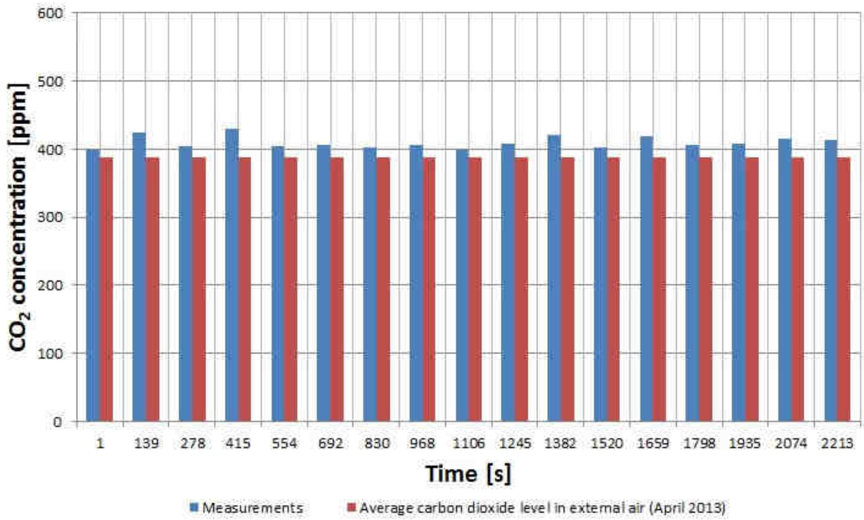

Fig. 7. Change of CO_2 concentration inside the boiler plant (+3.50 m) - April 2013

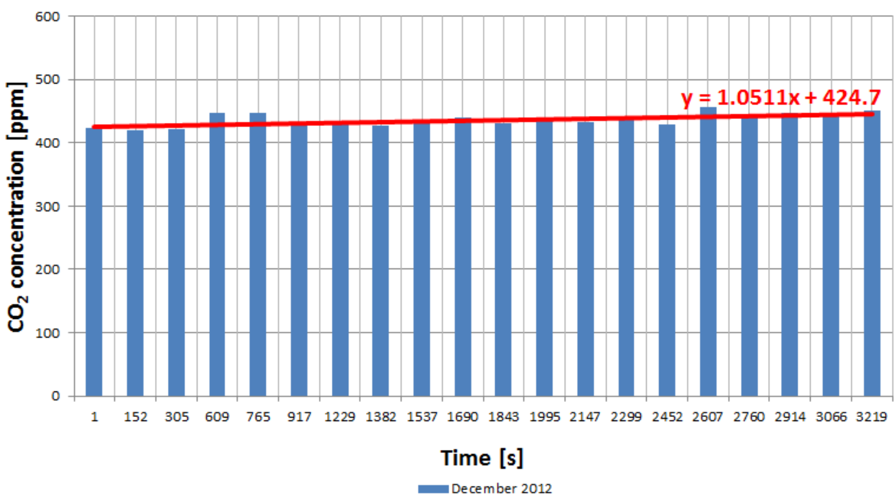

Fig. 8. Change of CO_2 concentration outside the boiler plant - December 2012

Interesting are also the changes of CO_2 concentrations inside the hospital boiler plant relative to the average concentration of CO_2 outside the boiler plant on the day of measurement (Figs. 10 and 11). They show by how much the air inside the boiler plant is more or less polluted than the air outside it (positive values indicate higher pollution of the indoor air, while negative values inform that the indoor air pollution is lesser than the average value for the outside air measured at the level of 1.50 m). Analyzing the results one can easily observe that inside the boiler plant higher concentrations occur at the level of 0.00 m. They are generally higher than the average concentrations of CO_2 outside the building which may indicate an emission of this pollutant into the room during operation of the boiler. Taking into account the density of CO_2 is not surprising that its concentration is lower at the level of 3.50 m.

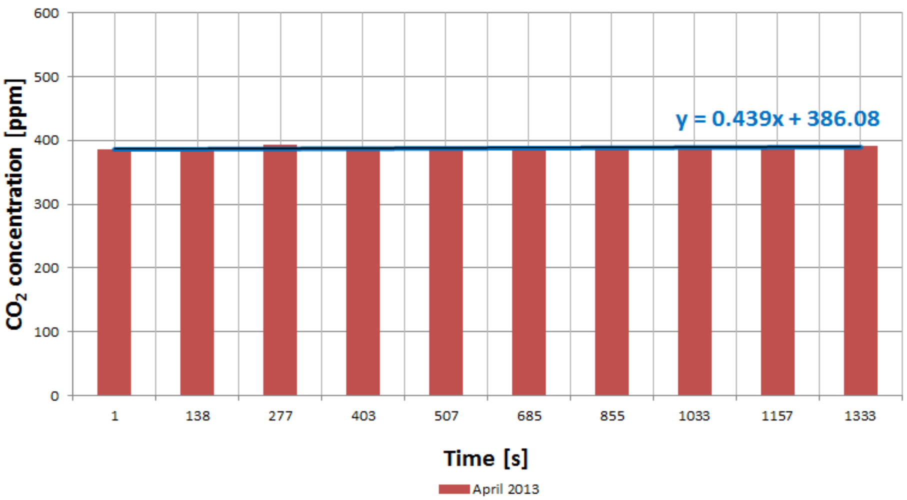

Fig. 9. Change of CO_2 concentration outside the boiler plant - April 2013

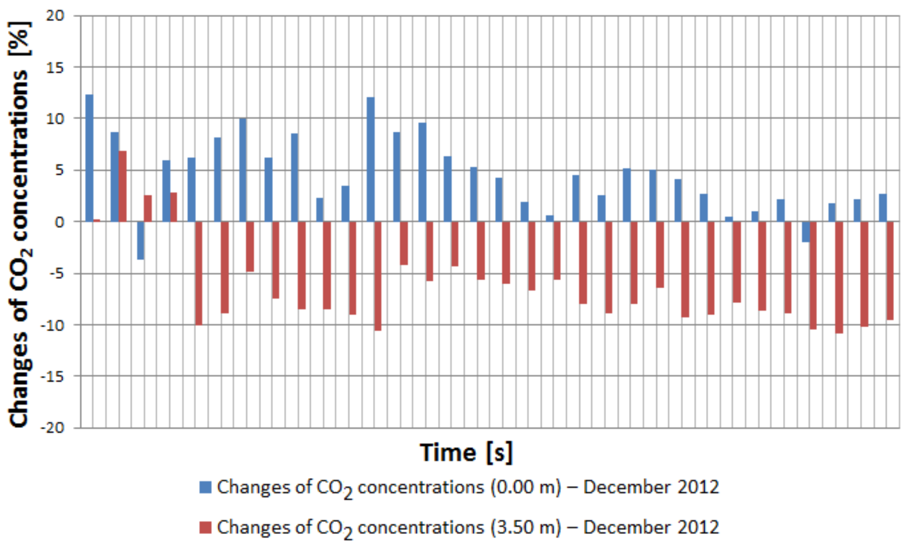

Fig. 10. Change of CO_2 concentration inside the boiler plant vs. average CO_2 concentration outside the boiler plant - December 2012

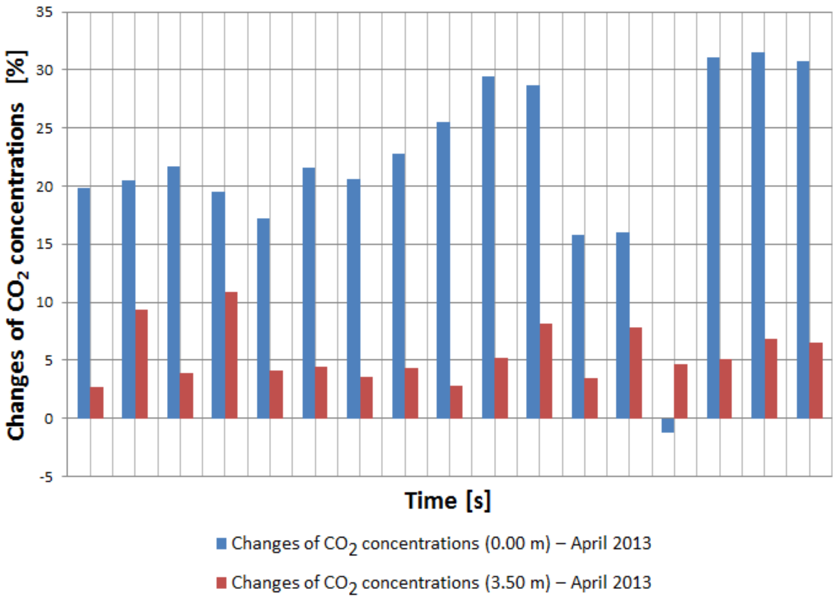

Fig. 11. Change of CO_2 concentration in the boiler plant vs. average CO_2 concentration outside the boiler plant - April 2013

Conclusions

The article presents results of measurements and analysis of the distribution of CO_2 concentrations inside and outside the building of a small boiler plant. The use of a gas microchromatograph enabled an accurate and quick measurement due to which it was found that the concentration of carbon dioxide did not depend on the outside air temperature. The resulting values were similar regardless of whether the measurements were conducted in December 2012 or April 2013. The impact of seasons on the levels of concentrations in the indoor air is noticeable. This is associated primarily with the demand for heat during the period, the frequency of stay of people in the workplace and the number of working devices. The influence of outside temperature and the time of year is also noticeable in the case of CO_2 concentration outside the building.

Information on changes in the concentration of carbon dioxide inside and outside the boiler plant is important not only for cognitive scientific reasons but also can serve as a guide for ventilation system designers. The impact on the results can have both ventilation (or its lack), people and equipment that are in the room, and the air change depending on the intended use of the building. After analyzing the measurements it can also be stated that the measured CO_2 concentrations even in the absence of mechanical ventilation do not affect people who work in the boiler plant, and thus do not cause any adverse symptoms.

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