JOURNAL OF APPLIED ENGINEERING SCIENCES
ISSN: 2247-3769 / e-ISSN: 2284-7197

VOL. 8(21), ISSUE 1/2018
ART.NO. 231, pp. 61-66

THE IMPACT OF CARBON DIOXIDE CONCENTRATION ON THE HUMAN HEALTH - CASE STUDY

P. Kapalo [a], F. Domniţa [b] *, C. Bacoţiu [b], Nadija Spodyniuk [c]

[a] Technical University of Kosice, Faculty of Civil Engineering, Department of Technical Building Equipment, Vysokoskolska 4, 04200 Kosice, Slovakia, e-mail: Peter.Kapalo@tuke.sk
[b] Technical University of Cluj-Napoca, Building Services Faculty, Department of Building Services Engineering, 21 Decembrie 1989 Boulevard 128-130, 400604 Cluj-Napoca, Romania, e-mail: florin.domnita@insta.utcluj.ro
[c] Lviv Polytechnic National University, Department of Heat and Gas Supply and Ventilation, St. Bandery 12, 79013 Lviv, Ukraine, e-mail: n_spoduniuk@meta.ua

Received: 12.02.2018 / Accepted: 24.03.2018 / Revised: 30.04.2018 / Available online: 31.05.2018

DOI: 10.2478/jaes-2018-0008

KEY WORDS: CO_2 concentration, heart-beat intensity, blood pressure, pulse, physical activity.

ABSTRACT:

From various other studies, it is known that the maximum carbon dioxide concentration in different countries is between 1,000 ppm up to 1,500 ppm. Therefore, the research is focused on indoor environment, namely the production of pollutants from the persons inside office rooms. The article presents the trend of the carbon dioxide concentration from the occupants inside an office. It is examined the carbon dioxide production separately for men and women, for persons of different mass and for persons of different ages. It is also analyzed the carbon dioxide production during a sedentary and physical activities. In parallel with the production of carbon dioxide is presented the monitoring of the human pulse and blood pressure. All these parameters are monitored together with relative humidity and indoor air temperature. The aims of this paper is to describe the partial results of human respiration impact on indoor air quality in closed spaces and to research the connection between carbon dioxide concentration and human health.

1. INTRODUCTION

Nowadays people spend more than 80 % (90 % in industrial countries) of their time indoors. As a consequence, there is a growing incidence of a new kind of disease related to bad indoor air quality, identified as building-related illnesses and sick building syndromes. High occupancy and intensive human activities can affect indoor environment by changing air composition and thus worsening the living conditions by increasing the carbon dioxide (CO_2) concentration. In industry, chemical contaminants and gaseous compounds are held responsible for the diseases mentioned above, since in buildings with limited natural ventilation and without a demand-controlled ventilation they can accumulate with time (Sironi et al, 2014).

By improving both the thermal properties and the air tightness of buildings, indoor air quality is affected, i.e. without proper ventilation (natural or mechanical) there is a significant deterioration of indoor air quality. Nowadays, people spend indoors more than 80% (even 90% in industrial countries) of their time. High occupancy and intensive human activities can affect indoor environment by changing air composition and thus worsening the living conditions (sick building syndrome) with consequences as increased values of indoor air relative humidity (mould on the inner side of the building envelope elements) or high CO_2 concentration levels. Also, the occupants do not have the possibility to adjust in real time the indoor air temperature in each room. For longer or shorter time periods, the humans had the feeling of insufficient ventilation of the rooms (lack of fresh air). An intensification of sick building syndrome symptoms was found by Lis and Ujma (2014), together with a worsening of the perception of indoor air quality by building occupants.

For this reason, there is an increasing interest in indoor air quality monitoring in order to improve our lives, reducing the causes of these illnesses, and to devise energy-efficient ventilation strategies. More than 40% of primary energy in Europe is consumed in buildings to ensure better indoor conditions for all the occupants, especially for heating, cooling and ventilation (Herberger et al, 2010).

Poor quality of indoor environment in buildings influences occupants comfort and even the work performance. Major issues were found in recently renovated buildings as: high concentrations of medium and large particles in the air, low levels of luminance (visual discomfort), relatively large CO_2

* Corresponding author: Florin Domnita, e-mail: florin.domnita@insta.utcluj.ro

concentration and high noise levels (acoustic discomfort). The results of Vilcekova et al. (2017) research, carried out in some university classrooms, confirm the close relationships between the quality of indoor environment and the learning performance of the students.

Also, the inadequate indoor air quality can significantly reduce the work performance in office buildings. In their study, Budarova and Vilcekova (2015) validate this assumption and determine a decreasing by 6% to 9% of office work productivity due especially to occupants concentration ability reduction. A field study about the influence of polluting agents (volatile organic compounds, particulate matters and CO_2) on occupants labour productivity was conducted by Vilcekova and Budaiova (2015) during heating and non-heating seasons in the office buildings in Slovakia. The conclusion was that in the buildings without controlled ventilation system, the concentrations of those pollutants in the indoor air quickly exceed the limit values and have a bad influence on productivity.

The CO_2 concentration is also closely related with ventilation intake rate, ventilation isolation reliability, leak tightness of the building, duration of the CO_2 releases, protective equipment, and clean purge air supplies, as applicable (Sarrack, 2012).

Przekop (2011) concluded that the occupants of a room with increased level of carbon dioxide concentration are making more effort to breathe, their hearts beat faster and the level of cells oxygenation is reduced. As a result, it occurs signs of earlier fatigue and lack of concentration in the workplace, which finally leads to a low professional performance and to low labour productivity.

A detailed method of evaluating how CO_2 concentration affects on the occupants of a building must take into account the measured or calculated concentration of CO_2 for each scenario of activities developed inside a room or another. Based on the data obtained from experimental measurements of the CO_2 concentration (Kapalo et al, 2014), were developed a methodology for determining the needed fresh air flow rate inside an office, very important for a proper ventilation system design in office buildings.

2. MATERIALS AND METHODS

This article presents two series of measurements carried out in three different rooms in order to establish a connection between the human activities carried out in this spaces and the indoor micro-climate. The first measurements were performed inside an office room with constant air exchange rate with outside, considering that it was occupied by one person. The second type of measurements were made with a different number of people and for two different and constant air exchange rates with outside. In both situations it were measured the CO_2 concentration, the air temperature, the pulse and the blood pressure.

The first experiment was performed inside room A with a floor area of 19.14 m^2 and a volume of 52 m^3. The measured ventilation rate was 0.2 h^{-1}, according to the methodology [8] and the volumetric air flow rate per person was 10.4 m^3/h. During the experiment, the room was inhabited by one adult, either a male of 53 years old and weighing 90 kg or a female of 25 years old and weighing 52 kg.

The measurements were divided in two phases. In the first one, it were measured some indoor air quality parameters, the pulse and the blood pressure for a seated office work on the computer. In the second phase, there were carried out the same measurements but for a much more intense physical activity (squats).

The second and the third experiments were carried out in another two enclosures, room B and room C, both occupied with a different number of persons.

Room B, with a floor area of 60 m^2 and a volume of 156 m^3, was inhabit with 9 people (four men and five women), whose average age was 37 and the average weight was 69 kg. All the occupants were doing an office work in a sitting position. The total volumetric air flow rate was 175 m^3/h and the volumetric air flow rate per person was 19.4 m^3/h.

Room C, with a floor area of 86 m^2 and a volume of 224 m^3, was occupied with 11 people (nine men and two women), whose average age was 28 and the average weight was 80 kg. The persons inside room C carried also sedentary office work. The total volumetric air flow rate was 527 m^3/h and the volumetric air flow rate per person was 47.9 m^3/h. During the experiments, the persons completed several questionnaires in order to obtain a subjective evaluation of their perception regarding the room's indoor climate. These studies are not the subject of the research presented in this paper.

In order to determine the values of carbon dioxide concentration it was used an air temperature and relative humidity measuring device Testo 435-4 with carbon dioxide sensor Testo 0632. The device measures with accuracy the CO_2 concentration for a measuring range from 0 ppm to 10,000 ppm. Its sensitivity is 75 ppm of CO_2 and the precision of this device is ±3%. The accuracy measuring range for temperature is from 0°C to +50°C and the precision is ±0,5%. The accuracy measuring range for relative humidity is from 0% to 100% and the precision is 1.8%. The working temperature range is between -20°C and +50°C. The devices were placed close to the centre of the occupied area at one meter height. For measuring the human pulse (heart-beat intensity) and blood pressure it was used the device Sanitas-SBM 42. The measuring range of this device is from 30 to 180 pulse/minute and its sensitivity is ±5%. The working temperature range is between -10°C and +40°C.

3. RESULTS

3.1 Indoor air parameters measurement inside room A

The measurements were divided into two phases, the first one involves all the measurements performed in the case of seated office work and the second one, the measurements carried out during intense physical exercises.

In the first phase there were performed two separate measurements. Each measurement was made for a single person at a time. These measurements were repeated for two different persons. The first measurement was performed for a man of 53 years old, weighing 90 kg and the second measurement it was carried out for a woman of 25 years, old weighing 52 kg (Table 1).

	Man 53 y, 90 kg		Woman 25 y, 52 kg	
Measuring time (min)	Blood pressure (mmHg)	Pulse pressure (mmHg)	Blood pressure (mmHg)	Pulse pressure (mmHg)
0	112/91	21	95/67	28
30	112/82	30	96/69	27
60	110/78	32	93/68	25
90	113/85	28	102/74	28
120	121/90	31	95/75	20

Table 1. Measured blood pressure and pulse pressure for office work seated activity

The measuring device Testo 435-4 with carbon dioxide sensor Testo 0632 recorded the air temperature and the CO_2 concentration. In the same time, Sanitas-SBM 42 device measures the blood pressure and the heart-beat intensity (pulse) of each person. The first phase corresponds to section A - B in the graphical variation of CO_2 concentration with time (Figure 1).

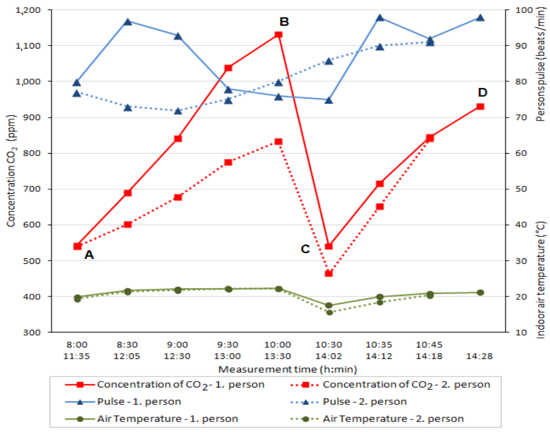

Figure 1. CO_2 concentration values and heart-beat intensity (pulse) of occupants in room A

In the second phase there were performed also two separate measurements with the same two persons. The measured values of pulse pressure and blood pressure are presented in Table 2. In this case, the graphical variation of CO_2 concentration with time is represented by section C - D (Figure 1). During the section B – C, room A has been intensively ventilated by opening the windows.

Table 2. Measured blood pressure and pulse pressure for intensive physical activity

	Man 53 y, 90 kg		Woman 25 y, 52 kg	
Measuring time (min)	Blood pressure (mmHg)	Pulse pressure (mmHg)	Blood pressure (mmHg)	Pulse pressure (mmHg)
0	115/90	25		
3			114/77	37
9	121/89	32	133/79	54
12				
15	115/83	32		
18			141/78	63
24	117/79	38		

During the measurements performed in room A the door and the windows were closed, thus the air exchange with outside has a constant value of 0.2 h^{-1}.

3.2 Indoor air parameters measurement inside room B

In room B, the measurements were made in the presence of 9 occupants, five women having from 25 to 44 years old and weighing from 50 kg to 66 kg and four men having from 25 to 41 y old and weighing from 67 kg to 90 kg. Room B was supplied with fresh air from outside through an air conditioner, whose volumetric air flow rate ensures 19.4 m^3/h for each person. This volumetric air flow rate does not satisfy the requirements of European Norms EN 15251 (2006) and EN 13779 (2007). EN 15251 (2006) requires a volumetric air flow rate per person of 25.2 m^3/h (rooms inside buildings classified in the second category - Standard level for new and reconstructed buildings). EN 13779 (2007) indicates a volumetric air flow rate per person of 45 m^3/h (room of IDA 2 category). In Figure 2 is presented the variation with time of CO_2 concentration, marked by the continuous line. While the measurement of CO_2 concentration was performed, the occupants carried out a seated office work on the computer. During the working hours, the door giving in corridor was opened frequently, because the shortage of fresh air. If the door giving in corridor was closed, the CO_2 concentration inside the room was even bigger.

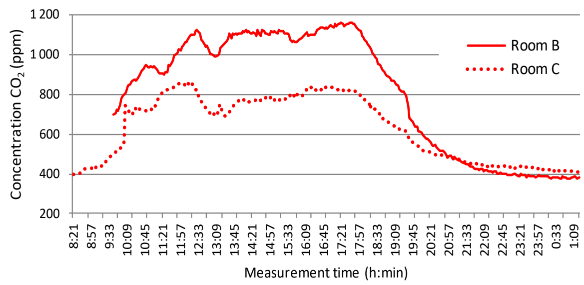

Figure 2. Variation with time of CO_2 concentration in rooms B and C

During the working 8 hours, there were carried out measurements of each person's heart-beat intensity (pulse) at four different moments of the day, as is shown in Figure 3.

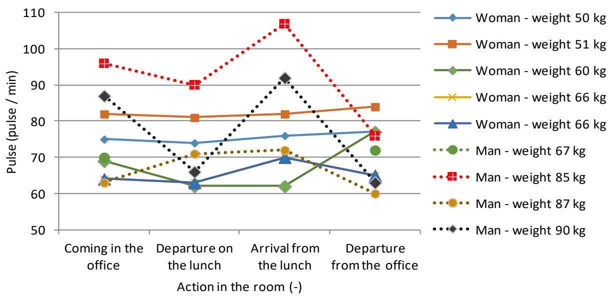

Figure 3. Heart-beat intensity (pulse) of occupants in room B

3.3 Indoor air parameters measurement inside room C

In room C, the measurements were performed in the presence of 11 occupants, two women having from 25 to 32 years old and weighing 50 kg and 68 kg and nine men having from 25 to 38 years old and weighing from 75 kg to 112 kg. Room C was supplied with fresh air from outside through an air conditioner, whose volumetric air flow rate ensures 47.9 m^3/h for each person. According to Persily (2005b) and Przekop (2011) this volumetric fresh air flow rate is appropriate for human comfort. While the measurement of CO_2 concentration was carried out, the occupants work on the computer, so they have rather a sedentary activity.

During the working hours, some of the occupants sometimes leave the office because of professional duties, so the door giving in corridor was frequently opened. In Figure 2 is presented the variation with time of CO_2 concentration, marked by the dotted line.

During the working 8 h, there were carried out measurements of each person's heart-beat intensity (pulse) at four different times of the day, as is shown in Figure 4.

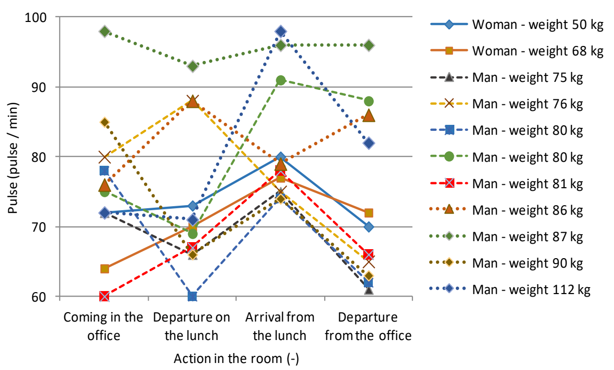

Figure 4. Heart-beat intensity (pulse) of occupants in room C

In Figure 3 and Figure 4 the values of the pulse for women are marked by continuous lines and the heart-beat intensity for men with dashed and dotted lines. In two cases, for two men (weighing 76 kg and 86 kg), during lunch break the pulse declines because they did not leave room C for lunch and remained to rest.

4. DISCUSSION

From the graphical variation of the CO_2 concentration, as shown in the Figure 1, it can be seen that, for a non intensive office work, the CO_2 concentration increases approximately constant - part A - B. For identical office activity, the heavier persons generate the increasing of CO_2 concentration in the office room more rapidly than lighter occupants. The increasing of air temperature is depending on the intensity of activity carried out in the room. The measured values of heart-beat intensity (pulse) did not have a common characteristic and were very unstable and fluctuating.

From Figure 1, it can be seen an approximately constant increase of CO_2 concentration for an intense physical activity (squats) as well as for a sedentary office work, the only difference being that, in the last case, the CO_2 concentration increases more rapidly. For intensive physical activity, it is obvious the increasing of pulse intensity for every occupant of the room B or C. Heavier persons has a more rapidly increase of pulse intensity as lighter persons. During the physical exercises the systolic blood pressure increases and the diastolic blood pressure decreases. In this manner, the difference between them (pulse pressure) increases, for younger persons more rapidly than for elder ones.

In the case of the man weighting 90 kg and having 53 years old, the calculated CO_2 mass airflow rate that is generated inside the room is 10.15 mg/s for sitting office work and 55 mg/s for intensive physical exercises. For the women weighting 52 kg and having 25 years old, the CO_2 mass flow rate is 8.2 mg/s for sitting office work and 45 mg/s for intensive physical exercises. The methodology of calculating the CO_2 mass flow rate is described by Kapalo et al (2014) and Persily (1987a and 2005b).

In rooms B and C it was not possible to ensure the door closed while measurements were performed and not all of the occupants remained in the room. The great advantage of this situation was that, in contrast with the measurements made in ideal conditions (room A – the door closed during measurements), the experiments performed in these two rooms show the real state of the variation with time of CO_2 concentration, typically for real buildings. In rooms B and C only HVAC ensures the needed fresh air flow rate. The cause was the fact that the infiltration air from outside was negligible because the windows could not be open. During the lunch break, the persons pulse increase because of the physical effort that was made on the way to lunch and back.

In room B, where the required fresh air flow rate was not achieved, the pulse intensity mostly declined, or only slightly increased (Figure 3). The decreasing of pulse may indicate an attenuation of occupants metabolism caused by the poor indoor air quality. In the afternoon, when the CO_2 concentration was of nearby 1,000 ppm, the pulse decline was more significant.

In room C, where the HVAC system provides enough fresh air, the pulse intensity of people was variable (Figure 4). In the morning, half of the people had low pulse intensity and the other half had an increased pulse. Throughout lunch, the pulse was increased for all people except two, who were not going for lunch and stayed in the room and rest. After lunch, almost all the persons had a low pulse, with the exception of just mentioned two persons. Low values of pulse may indicate an attenuation of occupants' metabolism, mainly for heavier weight people, caused by less physical activity.

5. CONCLUSIONS

The human health inside a building may be influenced mainly by indoor air temperature and freshness. As shown by the measurements of air parameters and occupants blood pressure and pulse, it can be stated that substantial changes of air temperature, air relative humidity and air cleanliness have important consequences on the activities carried out inside the room. For sitting office work, the experiments recorded fluctuating values of pulse intensity. As long as the intensity of physical activity increases significantly, the systolic pressure increases and the diastolic pressure decreases, which cause a widening of pulse pressure. As a consequence, the occupants of a room with increased level of carbon dioxide concentration are making more effort to breathe, which causes to earlier fatigue in the workplace and to low labour productivity (Seppanen et al, 2006). It can be concluded that the carbon dioxide concentration, measured or calculated inside a room, is the most adequate parameter of indoor air, based on which the ventilation equipment must operate in order to ensure the indoor air quality.

If the freshness of the air inside a room is poor (high values of CO_2 concentration), the humans pulse has lower values for heavier persons than for lighter occupants. As a consequence, the people weighing less are more responsive to high levels of CO_2 concentration than the heavier people.

Inside a room with constant shortage of fresh air, the heart-beat intensity increases by approximately 20% compared with a room where the fresh air is supplied with proper air flow rate. This means that a person inside an unventilated room has to perform with more effort in order to accomplish the work tasks and after the program is more fatigue. Thus, those people have a lower labour productivity and need much more time for recovery than people working inside a room with adequate rate of fresh air.

Nowadays, the ventilation systems designers give a special attention to the distribution devices in order to obtain a proper spreading of the supply fresh air into the occupied spaces. There is an increasing interest in monitoring the CO_2 concentration inside rooms by a continuous adjustment of ventilation rates, in order to improve the occupants comfort and to reduce the causes of indoor bad conditions (Savcenko et al, 2017).

Therefore, the proper design of the air distribution systems (diffusers) that ensure an efficient ventilation will help to create a healthy indoor environment all across a room, without stagnant air areas with CO_2 amassment risk (Voznyak et al, 2015, Muntea and Domnita, 2015). Creating a HVAC system, which should be designed in accordance with applicable legislation, it would create an optimal indoor environment for people in the occupied areas (Strakova and Takacs, 2017).

6. ACKNOWLEDGMENTS

This article was elaborated in the framework of the project VEGA 1/0697/17.

7. REFERENCES

Budarova, Z., Vilcekova, S., 2015. Assessing the effect of indoor environmental quality on productivity at office work. *Journal of Civil Engineering*, 10 (1), pp. 59-67.

EN 13779, 2007. *Ventilation for non-residential buildings. Performance requirements for ventilation and air conditioning equipment*. Slovak Standard - European Norm, pp. 72.

EN 15251, 2006. *Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics*. Slovak Standard - European Norm, pp. 51.

Herberger, S., Herold, M., Ulmer, H., Burdack-Freitag, A., Mayer, F., 2010. Detection of human effluents by a MOS gas sensor in correlation to VOC quantification by GC/MS. *Building Environment*, 45, pp. 2430-2439.

Kapalo, P., Vilcekova, S., Vozniak, O., 2014. Using Experimental Measurements of the Concentrations of Carbon Dioxide for Determining the Intensity of Ventilation in the Rooms. *Chemical Engineering Transactions*, 39, pp. 1789-1794.

Lis, A., Ujma, A., 2014. Changes in the External Environment and of Interior Microclimate as a Consequence of Energetic Modernization of Building. *Advanced Materials Research*, 1020, pp. 585-590.

Muntea, C., Domnita, F., 2015. Air movement measurement and simulation inside a standard cleanroom, produced by an inlet device with double exponential profile. *International Multidisciplinary Scientific Geoconference SGEM 2015, Albena, Bulgaria*, 1 (4): pp. 843–850.

Persily, A., 1997a. Evaluating building IAQ and ventilation with indoor carbon dioxide. *ASHRAE Transactions*, 103, pp. 193–204.

Persily, A., 2005b. What we think we know about ventilation? *10th International Conference on Indoor Air Quality and Climate "Indoor Air 2005", Beijing, China*, 2, pp. 24–39.

Przekop, R., 2011. Oxygen Transport in Human Alveolar Sacs. *Chemical Engineering Transactions*, 24, pp. 565-570.

Sarrack, A., 2012. Estimating Toxic Risk Exposure to Populations Inside Buildings. *Chemical Engineering Transactions*, 26, pp. 549-554.

Savchenko, O., Zhelykh, V., Voll, H., 2017. Analysis of the systems of ventilation of residential houses of Ukraine and Estonia. *XVI International Scientific Conference Košice-Lviv-Rzeszów "Current Issues of Civil and Environmental Engineering"*, Book of Extended Abstracts, pp. 1-8.

Seppanen, O., Fisk, W., Lei, Q., 2006. Ventilation and performance in office work. *Indoor Air Journal*, 18, pp. 28-36;
Sironi, S., Eusebio, L., Capelli, L., Remondini, M., Del Rosso, R., 2014. Use of an Electronic Nose for Indoor Air Quality Monitoring. *Chemical Engineering Transactions*, 40, pp. 73-78.

Strakova, Z., Takacs, J., 2017. Indoor air quality and mechanical ventilation for technology buildings. *Pollack Periodica*, 12 (2), pp. 141-150.

Vilcekova, S., Meciarova, L., Burdova, E. K., Kosicanova, D., Doroudiani, S., 2017. Indoor environmental quality of classrooms and occupants' comfort in a special education school in Slovak Republic. *Building and Environment*, 120, pp. 29-40.

Vilcekova, S., Budaiova, Z., 2015. Productivity and indoor environmental quality in offices. *International Multidisciplinary Scientific Geoconference SGEM 2015, Albena, Bulgaria*, 1 (4), pp. 993–1000.

Voznyak, O., Sukholova, I., Myroniuk, K., 2015. Research of device for air distribution with swirl and spread air jets at variable mode. *Eastern European Journal of Enterprise Technologies*, 6 (7), pp. 15-23.