UDC 624.012.45

P. Kapalo[*], F. Domnita[**], O. T. Voznyak[***]
[*]Technical University of Kosice, Institute of Architectural Engineering, (Slovakia),
[**]Technical University of Cluj-Napoca, Department of Building Services Engineering, (Romania),
[***]Lviv Polytechnic National University, Department of Gas Supply and Ventilation, (Ukraine)

INVESTIGATION OF INDOOR AIR QUALITY AND ITS IMPACT ON HUMAN ACTIVITY - CASE STUDY

Наведено часткові результати впливу людської присутності на якість повітря в приміщенні в досліджуваній офісній кімнаті. Температура повітря в приміщенні, відносна вологість і концентрація діоксиду вуглецю реєструються в досліджуваному приміщенні під час роботи. Одночасно визначають серцебиття (пульс) і кров'яний тиск респондентів. У процесі вимірювань досліджуване приміщення було зайняте лише однією людиною. Ці виміри було повторено декілька разів. Респонденти були різної статі, різної ваги і різного віку. Виміри проводили за такої інтенсивності роботи: сидяча робота в офісі, з використанням комп'ютера, вправи на присідання і вправи на велотренажері. Метою дослідницької роботи є визначення взаємозв'язку між інтенсивністю роботи і зазначених факторів. Вимірювали пульс та артеріальний тиск респондентів з метою вивчення впливу їх зміни на якість повітря у приміщенні. Отримані граничні умови матимуть позитивний вплив на створення комфортного внутрішнього мікроклімату середовища. Можна зробити висновок про те, що концентрація діоксиду вуглецю, яка вимірюється або обчислюється всередині приміщення, є найбільш відповідним параметром повітря в приміщенні, на підставі чого повинно працювати вентиляційне обладнання для забезпечення якості повітря в приміщенні. Оптимально розміщені пристрої, датчики і відповідна система автоматизації може ефективно підтримувати якість повітря в приміщенні на комфортному рівні.

Ключові слова: вимір, двооксид вуглецю, температура, артеріальний тиск, частота серцевих скорочень.

This paper presents the partial results of human presence impact on indoor air quality in a monitored office room. Indoor air temperature, relative humidity and carbon dioxide concentration are recorded in the investigated room during the operation. Simultaneously, the heartbeat (pulse) and blood pressure of respondents are determined. During the measurements, the investigated room was occupied only by one person. These measurements were repeated several times. Respondents were of different sex, different weight and different age. Measurements were carried out during activities: sedentary office work using computer, exercises for squat and exercises on the stationary bike. The aim of the research work is to determine the relationship between the activities and the determined mentioned factors. Measurements of the heartbeat and blood pressure of respondents were realized in order to investigate the impact of their variation on perceived indoor air quality. The obtained boundary conditions will have a positive contribution to a healthy indoor environment. It can be concluded that the carbon dioxide concentration, measured or calculated inside a room, is the most appropriate parameter of indoor air, based on which the ventilation equipment must operate in order to ensure the indoor air quality. Optimally placed air quality devices and sensors and an appropriate automation system can effectively maintain the indoor air quality at comfortable levels.

Key words: measurement, carbon dioxide, temperature, blood pressure, pulse.

Introduction. By improving the thermal properties and also the air tightness of buildings, there is a change of indoor air quality in buildings – without any ventilation (natural or mechanical) there is a significant deterioration of indoor air quality. In low energy buildings, the ventilation is provided usually only by ventilation systems and as a consequence, they have a very important role. In case of a shortage of fresh air inside a room, people cannot open the window and ventilate the room naturally. New buildings need new ways of operation and new environments for the occupants [1].

A building is designed based on a given number of persons (occupants) which determines the needed rate of fresh air. During the building operation, the airflow rates required for maintaining the air freshness are difficult to change. Problems usually occur when, suddenly, the number of persons inside the room changes, even if is only for a short time. It is therefore very important to know the operating mode of the building for a longer period of time in order to make a proper design project of the building ventilation systems [2]. The deficit of fresh air can cause a decrease of professional performance of employees by the way of reducing concentration on the work performed. It is also possible to occur signs of fatigue and even it may cause disease [3]. 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 sitting at desk or during physical activity. 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 [4, 5]. The aim of the article is to obtain values of carbon dioxide production for people in different kind of activities. The data obtained can be useful in designing the ventilation systems in office buildings [6].

Materials and methods. Experimental room is an office located on the second floor in the five storey building (Fig. 1). During the research, the selected room was occupied by one adult person (Mahyuddin and Awbi, 2012; Kapalo et al. 2014). The sizes of the office, where the experimental measurements were carried out, are: length: 5.63 m, width: 3.40 m and height: 2.72 m. The office window room has the following dimensions: height: 1.75 m and width: 1.10 m. The volume of the room is 52 m^3 and the floor area is 19.14 m^2.

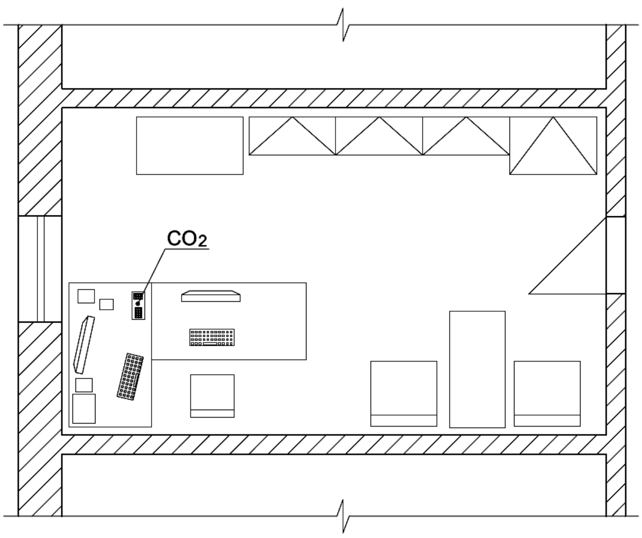


Fig. 1. The plan of the experimental office with the position of the CO_2 sensor

In order to determine the values of carbon dioxide concentration it was used the air temperature and relative humidity measuring device Testo 435-4 with carbon dioxide sensor Testo 0632. The device measures with accuracy the carbon dioxide concentration for a measuring range from 0 ppm to 10,000 ppm. Its sensitivity is 75 ppm of carbon dioxide 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 a height 1 m. 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.

Considering one person in the room, the measurements were divided into two phases. In the first phase, it were carried out the measurements of the indoor air parameters and the measurements of blood pressure while the occupant was doing an office work in a sitting position. The second phase of measurements involves the same parameters as in the first one while the occupant was doing either squats or stationary bike cycling.

Indoor air parameters measurement – first phase. In the first phase, there were performed four separate measurements. Each measurement was performed for a single person at a time. These measurements were repeated for four different persons. The first measurement was performed for a man of 53 years old weighing 90 kg, the second measurement was performed a man of 34 years old weighing 85 kg, the third was a woman of 33 years old weighing 58 kg and the fourth measurement it was made for a woman of 25 years old weighing 52 kg (Table 1).

The measuring device Testo 435-4 with carbon dioxide sensor recorded the concentration of carbon dioxide, the air temperature and relative humidity. Average indoor air temperature was 22 °C. Average indoor air relative humidity was 29,5 %. During the measurement of indoor air parameters, there were also measured the blood pressure and the heart-beat intensity (pulse) of each person. The some measured values are presented in Table 1 and in Figure 2.

Table 1

Measured blood pressure and pulse pressure for sitting activity

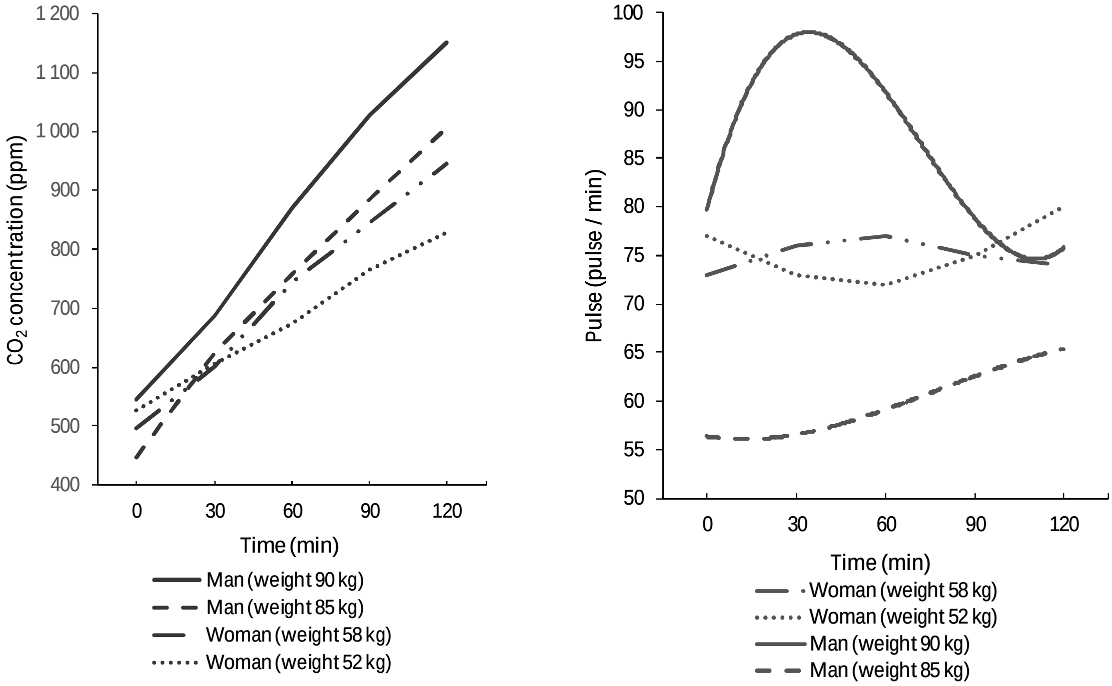
	1 – Man, 53 years, 90 kg		2 – Man, 34 years, 85 kg		3 – Woman, 33 years, 58 kg		4 – Woman, 25 years, 52 kg	
Measuring time (min)	Blood pressure (mmHg)	Pulse pressure (mmHg)	Blood pressure (mmHg)	Pulse pressure (mmHg)	Blood pressure (mmHg)	Pulse pressure (mmHg)	Blood pressure (mmHg)	Pulse pressure (mmHg)
0	112/91	21	123/77	46	97/59	38	95/67	28
30	112/82	30	121/74	47	81/58	23	96/69	27
60	110/78	32	100/70	30	9953	46	93/68	25
90	113/85	28	117/77	40	103/62	41	102/74	28
120	121/90	31	103/68	35	108/59	49	9575	20

Indoor air parameters measurement - second phase. In the second phase, there were performed three separate measurements. Each measurement was performed for a single person at a time. These measurements were repeated for two persons. The first measurement was performed during intensive squats for a man of 53 years old, weighing 90 kg. The second measurement was carried out for a woman of 25 years old, weighing 52 kg, also during intensive squats. The third measurement was performed for a man of 53 years old, weighing 90 kg, during stationary bike cycling.

Measuring devices recorded the same parameters: the carbon dioxide concentration, the indoor air temperature and relative humidity. Average indoor air temperature was 20 °C. Average indoor air relative humidity was 34 %. During the measurement of indoor air parameters, there were also measured the blood pressure and the heart-beat intensity (pulse) of each person. The some measured value are documented in Table 2, Figure 3.

During cycling it was not recorded the blood pressure regularly. It was recorded only the pulse - see dash-and-dot line on fig. 3b. The stationary bike was running at 48 RPM (rotation per minute) –

i.e. 17 km/h, for the whole duration of the experiment. At the end of cycling activity, it was measured the blood pressure (127/91 mmHg) and the pulse (105 pulse/min).



a *b*

Fig. 2. Variation with time of: a – carbon dioxide concentration,
b – heart-beat intensity (pulse) for sitting activity

Table 2

Measured blood pressure and pulse pressure for intensive physical activity

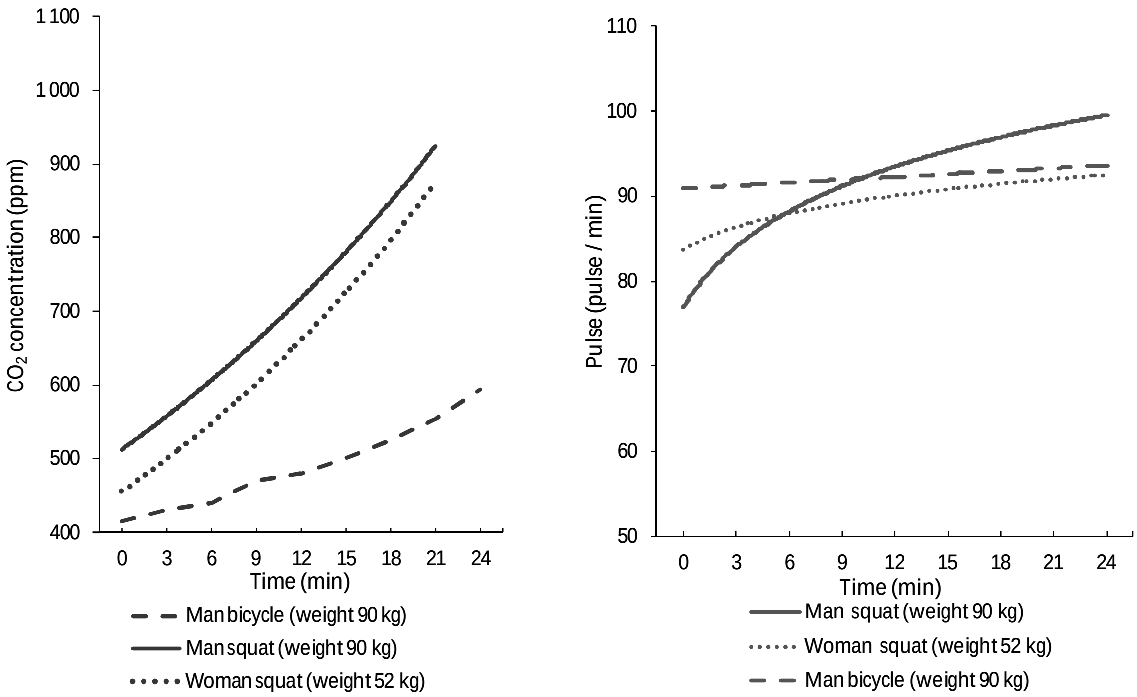
Measuring time (min)	1 – Man, 53 years, 90 kg		4 – Woman, 25 years, 52 kg	
	Blood pressure (mmHg)	Pulse pressure (mmHg)	Blood pressure (mmHg)	Pulse pressure (mmHg)
0	115/90	25		
3			114/77	37
9	121/89	32	133/79	54
12				
15	115/83	32		
18			141/78	63
24	117/79	38		

Calculating the fresh air ventilation airflow rate. Based on the value of the measured carbon dioxide concentration of outdoor air and indoor air was calculated the ventilation airflow rate caused by infiltration [7, 8] and it result a value of 0.2 1/h.

By means of the methodology for calculating the fresh air ventilation airflow rate based on carbon dioxide concentration [4, 5], first it is calculated the mass flow rate of carbon dioxide. The increasing of CO_2 concentration can be mathematically described by the following formula:

$$C_{IDA} = C_{SUP} + \frac{q_{ms}}{q_v}\left\{1 - \exp\left[\left(\frac{-q_V}{V_M}\right)t\right]\right\} \tag{1}$$

where C_{IDA} is the concentration of carbon dioxide in indoor air at the time t, in [g/m^3], C_{SUP} in the concentration of carbon dioxide in supply air (outdoor air) at the time t, in [g/m^3], qms is the carbon dioxide releases inside the room from the human source, in [g/s], q_V is the required airflow rate for room ventilation, in [m^3/s], V_M is the room volume, in [m^3], and t is the time, in [s].



a *b*

Fig. 3. Variation with time of: a – carbon dioxide concentration, b – heart-beat intensity (pulse) for intensive physical activity

According to STN EN 13779 [2], it is calculated the ventilation rate by using equation (2):

$$n = \frac{q_{ms}}{(C_{IDA} - C_{SUP}) \cdot V_M}. \tag{2}$$

Considering the maximal admissible carbon dioxide concentration of 1,000 ppm, for the man weighting 90 kg and having 53 years, the required fresh air ventilation airflow rate results 0.7 1/h for sitting office work and 4.6 1/h for intensive physical exercises.

Discussion. From the graphical variation of the carbon dioxide concentration as shown in the Figure 3, it can be seen that, for a non intensive office work, the CO_2 concentration increases approximately constant. For identical office activity, the heavier persons generate the increasing of carbon dioxide concentration in the office room more rapidly than lighter occupants. The measured values of blood pressure and pulse did not have a common characteristic and were very unstable and fluctuating. From Figure 3 it can be seen an approximately constant increase of carbon dioxide concentration as well as for sitting office work, but increases more rapidly. For intensive physical activity, it is obvious the increasing of pulse intensity for every occupant. Heavier persons has a more rapidly increase of the pulse intensity as the 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, the calculated carbon dioxide 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 the carbon dioxide mass flow rate is 8.2 mg/s for sitting office work and 45 mg/s for intensive physical exercises.

Conclusions: The human health inside a building may be influenced mainly by the indoor air temperature and air cleanliness. 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 blood pressure and pulse intensity. When 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 can result to earlier fatigue in the workplace and to low labor productivity [9]. From the research [10, 11] is evident that the dynamic microclimate can greatly improve the indoor climate environment.

It can be concluded that the carbon dioxide concentration, measured or calculated inside a room, is the most appropriate parameter of indoor air, based on which the ventilation equipment must operate in order to ensure the indoor air quality. The indoor air temperature and relative humidity must also be considered for a safety and comfortable environment. Optimally placed air quality devices and sensors and an appropriate automation system can effectively maintain the indoor air quality at comfortable levels. Location and placement of sensors for different operations of the ventilation system will be part of a further research.

Acknowledgement. This article was elaborated in the framework of the project VEGA 1/0307/16.

1. Pilipova I, Vilcekova S. Occupants comfort and performance in building with smart elements – a case study. 2013. International Journal of Construction Engineering and Management, vol. 2(4), 113–121. 2. STN EN 13779. 2007. Slovakian Standard - European Norm, Ventilation in nonresidential buildings. General requirements for ventilation and air conditioning equipment. 62 pages. 3. Koskela H, Maula H, Haapakangas A, Moberg V. and Hongisto V. 2014. Effect of low ventilation rate on office work performance and perception of air quality – a laboratory study. In: Proceedings of Indoor Air 2014, Hong-Kong, Vol. 2, pp. 673–675. 4. Kapalo P., Vilčeková S., Voznyak O. Using experimental measurements the concentrations of carbon dioxide for determining the intensity of ventilation in the rooms. Chemical Engineering Transactions, impact factor. Vol. 39, 2014 ISBN 978-88-95608-30-3; ISSN 2283-9216, – p. 1789–1794. 5. Kapalo P. Analysis of ventilation rate and concentrations of carbon dioxide in the office Lviv. Visnik National University Lviv Polytechnic, Ukraine. September 2013. P. 69, ISSN 0321-0499. 6. Mahyuddin N. and Awbi H.B. 2012. A Review of CO2 Measurement Procedures in Ventilation Research. International Journal of Ventilation, vol. 10(4), 353–370. 7. Persily A. 1997. Evaluating building IAQ and ventilation with indoor carbon dioxide. ASHRAE Transactions, Vol. 103, 193–204. 8. Persily A. 2005. What we think we know about ventilation? In: Proceeding of the 10th International Conference on Indoor Air Quality and Climate "Indoor Air 2005", Beijing, China, Vol. 2, pp. 24-39. 9. Seppanen O, Fisk W. and Lei Q.H. 2006. Ventilation and performance in office work. Indoor Air Journal, vol. 18, 28–36. 10. Voznyak O. T. Dynamichnyj mikroklimat ta energooshchadnist – Visnyk Nats. Un-tu "Lvivska politehnika" № 460 "Teploenergetyka. Inzhenerija dovkillia. Avtomatyzatsija", 2002 (in Ukrainian) – C. 150–153. 11. Voznyak O. T. Air distribution in a room at pulsing mode and dynamic indoor climate creation. Cassotherm 2015, Non-Conference Proceedings of Scientific Papers - KEGA Year of publishing: 2015. Technical universzy of Kosice, Slovakia, ISBN: 978-80-553-1873-8052, pp. 31–36.