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DETERMINATION OF THE VOLUME AIR EXCHANGE IN THE APARTMENT

Сьогодні у будівельній галузі є тенденція будувати будівлі, які споживають мало енергії. Для зниження тепловтрат будівелі теплоізолюються, а також збільшується герметичність будівель. Внаслідок поліпшення повітронепроникності будівель відбувається зміна якості повітря всередині приміщень. Без природної або механічної вентиляції спостерігається значне погіршення якості повітря у приміщенні. Для підвищення якості повітря в приміщенні використовують систему примусової механічної вентиляції за допомогою зондування вуглекислого газу. Завдяки цьому явищу є можливість обчислення масової витрати вуглекислого газу для різної інтенсивності роботи у приміщенні. Описано обчислення масової витрати вуглекислого газу для різної активності роботи у квартирі. Розрахунок зроблено відповідно до реально виміряної кількості вуглекислого газу в квартирі. За розрахованою масовою витратою визначають необхідну кількість свіжого повітря у квартирі. Метою роботи є визначення необхідної витрати повітря у приміщенні на основі вимірювання вмісту вуглекислого газу. Відповідно до обчислення підтримується комфортний рівень якості повітря у приміщенні. Розрахункова витрата повітря повинна оптимізувати капітальні та експлуатаційні витрати вентиляційного обладнання. Організована вентиляція може запропонувати нові технічні засоби для якості повітря в приміщеннях комплексних будівель. Наша мета не тільки поліпшити енергетичну ефективність системи вентиляції, а й забезпечити сприятливе для здоров'я внутрішнє повітряне середовище.

Ключові слова: якість внутрішнього повітря, двоокис вуглецю, масова витрата, квартира.

Currently in the building industry is trend to build buildings consuming little energy. For the aim reducing heat loss buildings they are building insulated and also air tightness of buildings increases.. By improving the air tightness of buildings, there is a change of indoor air quality in buildings. Without natural or mechanical of ventilation there is a significant deterioration of indoor air quality. For the raising of quality indoor air is optimal system with demand-controlled ventilation using sensing of carbon dioxide. From sensing of carbon dioxide is possibly calculated mass flow of carbon dioxide for various type of rooms and various activity in them. In article is documented the calculation of mass flow of carbon dioxide for various activity in the apartment. The calculation is elaborated as per real measured of carbon dioxide in the apartment. From the calculated mass flow is calculated volume air flow necessary for provision fresh air in the apartment. The aim of the paper is to determine the needed airflow rate in an occupied room, based on carbon dioxide measurement. Accordingly is calculation, in order to maintain a comfortable level of indoor air quality. The calculated airflow rate should optimize the investment and the operating costs of ventilation equipment. Controlled Ventilation has to offer new technical tools for the indoor air quality of complex buildings. Our aim is not only improve the energy efficiency of the ventilation system, but also to ensure a healthy indoor environment.

Key words: indoor air quality, carbon dioxide, mass flow, apartment.

Introduction. The trend in building construction area is to build living spaces with low energy demanding. The aim of reducing the building energy consumption is mainly to save resources for building operation but also to reduce the environment pollution. For the purpose, the buildings are more thermally insulated, the air tightness of buildings increases and the rooms are without opening windows. This trend requires a very quality and thorough design of building ventilation system, in order to prevent an uncomfortable indoor environmental. The problem is that, when we try to reduce the outdoor air pollution, it may occurs the deterioration of the indoor environment. Considering the today's society way of life, the people spend more time in buildings and that is why we have to ensure a high indoor air quality. It is therefore very important to ensure consistency thorough in designing of ventilation equipment for creating a clean and healthy indoor environment.

This article refers to monitoring the carbon dioxide concentration produced by humans during their stay in a residential room and, after that, to determine the mass flow rate of emerging pollutants and, in the end to calculate the fresh air volumetric airflow rate needed to ensure a healthy indoor environment.

Material and methods. The whole process of calculation is based on experimental measurements performed in a three-room apartment with a 204 m^3 volume of air, occupied by four persons.

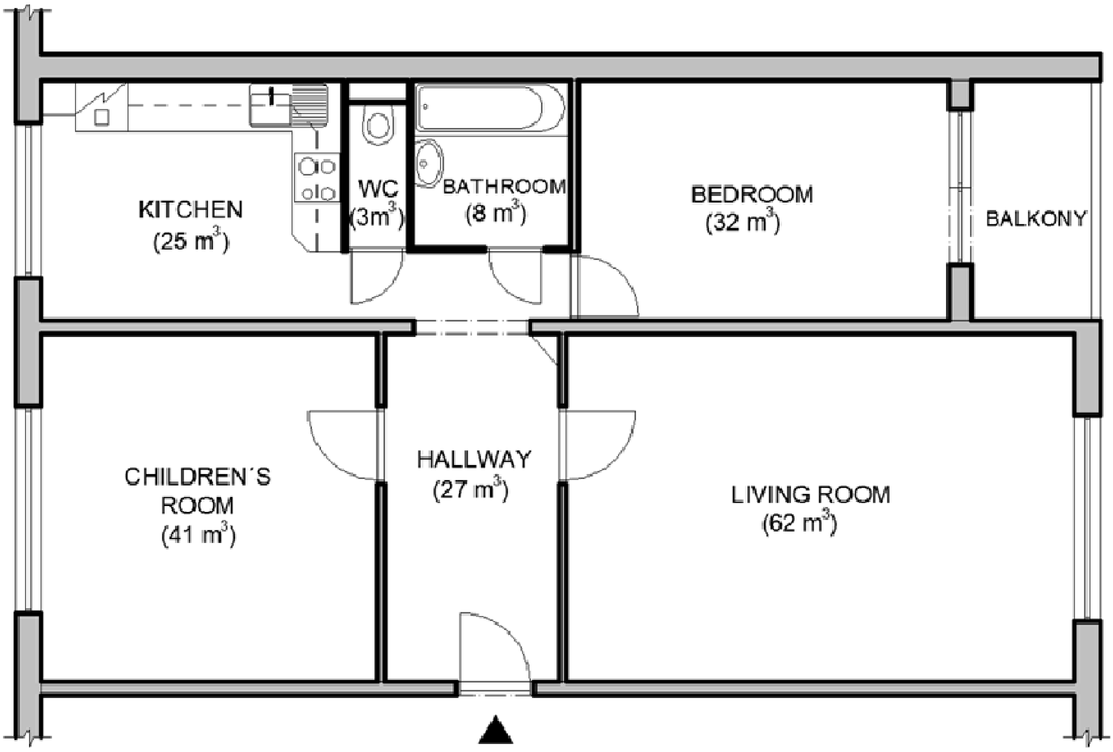

Fig. 1. The apartment plan showing the volume of each room.

In each room it was measured carbon dioxide concentration and, based on these values, it was then calculated the intensity the uncontrolled ventilation caused by leakages through building elements. Considering these values known, in this paper is presented a method to calculate mass flow rate of the increased pollutants and consequently, the required volumetric fresh airflow rate in every room of the apartment.

Measurement of indoor air parameters. The measurements were carried out separately for each apartment room. In every room the measurements were carried out during a whole week, from Monday to Sunday. The aims of measurements was to find out the variation of indoor air parameters during each day, while the apartment was occupied by a standard family. In Figure 2 is presented the measured average carbon dioxide concentration of indoor air in each apartment room.

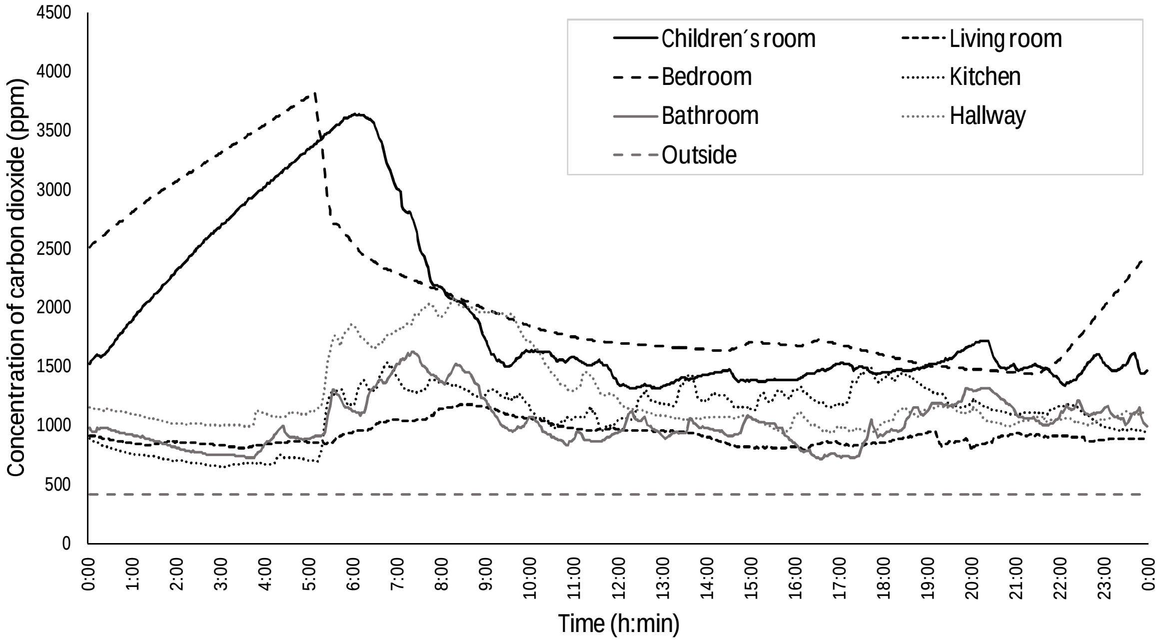

Fig. 2. Average carbon dioxide concentrations for each room in the apartment.

From Figure 2 it can be seen that the maximum value of carbon dioxide concentration is establish at night when people are asleep. During night hours sleep, all the doors in rooms are closed and no ventilation is provided through them and similarly, the ventilation through all the windows is not considered. A rapidly decrease of carbon dioxide concentration in the morning, after sleep, was caused by opening all the windows in all rooms. After that, in the following hours of the day it is less concentration of carbon dioxide in individual rooms. The indoor air quality during the whole day did not reached to the same level as outside air. It is necessary to be taken into account the fact that in Figure 2 is presented the course of the average value of CO_2 concentration, calculated on the base of carbon dioxide concentration measured during the seven days of the week. It is clear that residents of the apartment were acclimated in the apartment. The progressive deterioration of indoor air quality was very slow, so residents did not felt the change in air quality and thus, they did not considered necessary to ventilate the room.

Pollutants (carbon dioxide) mass flow rate calculation. The main monitored pollutant in the apartment is carbon dioxide. On the base of the measured values of carbon dioxide concentrations, there were calculated the mass flow rate of carbon dioxide, which is released by each room. The mass flow rate of pollutants was calculated by using the formula (1):

$$q_{m\check{s}} = \frac{q_V \cdot \left[C_{SUP} - (C_{IDAB} - C_{IDAA})\right]}{\left\{1 - e^{\left[\left(\frac{-q_V}{V_M}\right) . t\right]}\right\}} \qquad [\text{mg/s}] \qquad (1)$$

where: q_{ms} – mass flow of pollutants [mg/s]; q_V – volumetric air flow rate produced by uncontrolled ventilation (infiltration) [m^3/s]; $C_{IDA,A}$ – carbon dioxide concentration at the beginning of CO_2 concentration increase [mg/m^3]; $C_{IDA,B}$ – carbon dioxide concentration at the end of CO_2 concentration increase [mg/m^3]; C_{SUP} – outdoor carbon dioxide concentration [mg/m^3]; t – time of CO_2 concentration increase [s]; V_M – volume of the room [m^3].

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

$$\text{n} = \frac{q_{ms}}{\left(C_{IDA} - C_{SUP}\right) \cdot V_M} \qquad [1/\text{s}] \qquad (2)$$

The resulting values for pollutant mass flow rate and the necessary ventilation rate for each analyzed room are given in Table 1.

Table 1

The calculated values of pollutant mass flow rate

Type of room	Ventilation rate	Time of measurement	Concentration of carbon dioxide			Mass flow rate of carbon dioxide	Necessary ventilation rate
			Oudoor air	At the start	At the end		
	[1/h]	[s]	[mg/m^3]	[mg/m^3]	[mg/m^3]	[mg/s]	[1/(h.pers)]
Hallway	0,40	1080	755	2032	4126	18	61
Living room	0,23	600	755	1752	2299	11	38
Children´s room	0,11	1200	755	3883	3757	15	53
Kitchen	0,44	1080	755	1525	4371	26	89
Bathroom	0,52	720	755	955	2955	15	50

Based on carbon dioxide mass flow rate and on calculated volumetric air flow rate needed per person, it can be determined the volumetric air flow rate needed for a proper ventilation in entire apartment.

Discussion. From the calculated values of uncontrolled ventilation rate, caused by the leakages through building elements, it can be stated that, in the apartment rooms, there is not the same natural air exchange. Also, the calculated carbon dioxide mass flow rates are very different for each room. The difference between the calculated values of mass flow rates is caused by the different activities developed by rooms occupants. In the hallway, where the calculated mass flow rate is 18 mg/s, there were no intensive physical activities such as slow walking and movement, storytelling. In the living room (mass flow rate of 11 mg/s), there were passive activities such as resting in a sitting, reading books, watching TV. In the children's room (mass flow rate of 15 mg/s), the physical activities were more intensive. In the kitchen (mass flow rate of 26 mg/s), it occurs, in addition to other activities of persons, the burning of natural gas for cooking. In the bathroom (mass flow rate of 15 mg/s), it was performed movement only during washing.

Table 2

The effect of carbon dioxide concentrations on persons

Concentrations of carbon dioxide (ppm)	The effect on occupants
330 - 400	Outdoor air – fresh air
450 – 1000	The pleasant feeling - good level
1 000 – 2000	Sleepiness - bad air
2000 – 5000	Possible headaches,

For each activity, it was calculated the volumetric flow rate of fresh air needed to ensure a healthy indoor environment. It was assumed a maximum concentration of carbon dioxide of 1,000 ppm. If we want to achieve a entirely healthy indoor environment, we need a level of indoor air carbon dioxide concentration as close as possible to the carbon dioxide concentration from outdoor fresh air (Table 2).

Table 3

Required volumetric fresh air flow rate

		Necessary air flow rate [m^3/(h.pers)] for various carbon dioxide mass flow rates			
Carbon dioxide mass flow rate		*11 mg/s*	*15 mg/s*	*18 mg/s*	*26 mg/s*
Indoor air carbon dioxide concentration [ppm]	*1000*	38	53	61	89
	900	46	64	74	108
	800	58	81	93	136
	700	79	110	127	185
	600	122	170	197	287

For a better understanding, it was made a graphical representation of required volumetric air flow rate for different values of carbon dioxide mass flows rates (Fig. 3).

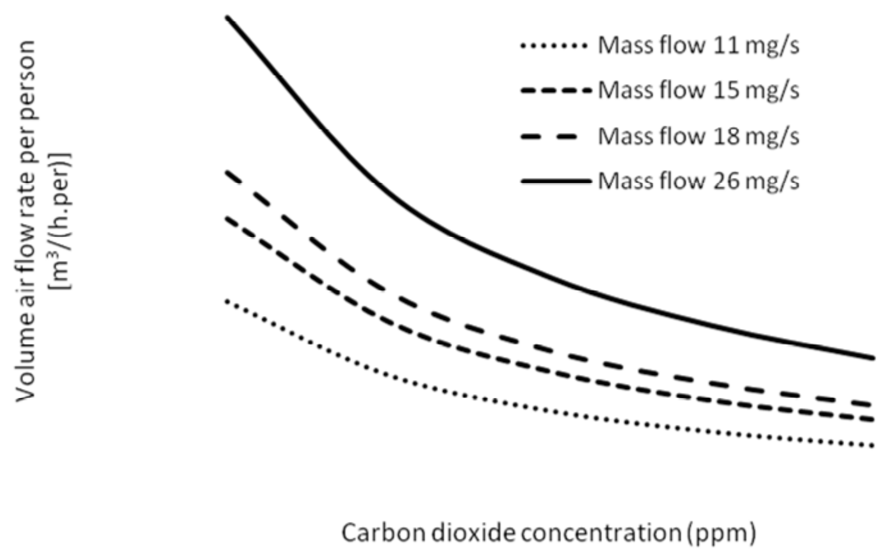

Fig. 3. Volumetric air flow rate per person.

As it can be seen from the graphical representation, it can be concluded that, for a better quality of indoor air we are going to need a bigger quantity of fresh air, whose volumetric flow rate will be increasing logarithmically. As we presumed, that in the apartment live 4 people, we can make a preliminary calculation for the needed fresh air flow rate in order to choose a proper ventilation system, working with no unnecessary energy costs (Fig. 4).

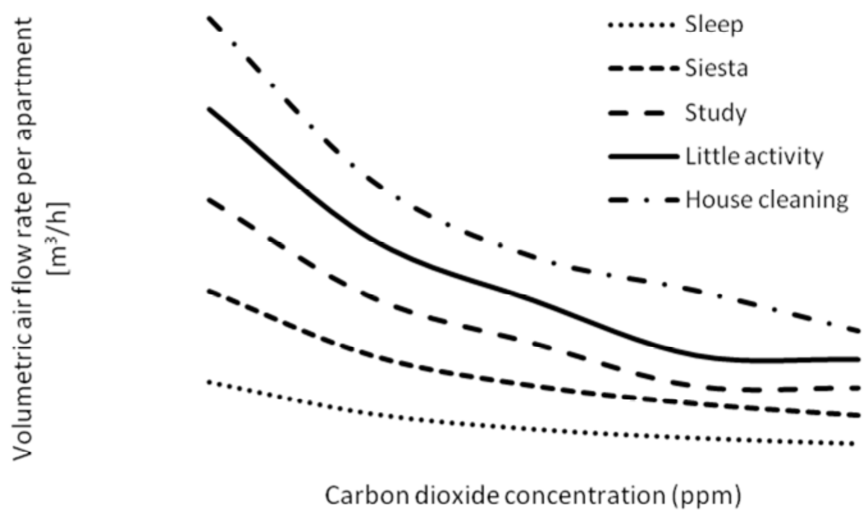

Fig. 4. Volumetric air flow rate per apartment

From the graphical representation of required volumetric air flow rate for the entire apartment, it can be seen that, for a normal way of living inside an apartment, we need to maintain the carbon dioxide concentration around 1,000 ppm. This means a proposed ventilation equipment with an airflow rate of 400 m^3/h. For a better indoor air quality, the proposed ventilation system must work with an airflow rate up to 1,000 m^3/h.

Conclusions. In terms of room air cleanliness, the major source of pollutants inside an apartment are the humans, which in every carried activity produces more or less pollutants. A healthy adult, which is carrying out a moderate activity, inhales about 0.4 % of oxygen and exhales about 4 % of carbon dioxide per minute. He inhales and exhales from 7.5 to 8 litre per minute, for about 15 breathe per minute. If he perform an intensive physical activity, when it is necessary a bigger volume of oxygen, the inhale/exhale volume increases.

From the experimental measurements carried out for determining the carbon dioxide concentration in the apartment, it was establish the real course of indoor air quality during the operation of the apartment. Based on the real values of carbon dioxide concentration, it was calculated the mass flow rate of pollutants - in our case the carbon dioxide, for different types of activities carried out in the apartment. Further, from the carbon dioxide mass flow rate, it was calculated the required volumetric airflow rate in order to reach the demanded level of indoor air quality. For night resting (sleeping) of the whole family, it is required the lowest volumetric fresh airflow rate (69 m^3/h) to achieve clean air (carbon dioxide concentration of 1,000 ppm). If we want to achieve a higher air quality, with a carbon dioxide concentration of 600 ppm, we need a volumetric fresh airflow rate up to 222 m^3/h.

Similarly, for physically more demanding activities, the needed fresh airflow rate will be considerably higher. For example, if the whole family will do the household cleaning, it will be needed fresh airflow rate from 345 to 1,112 m^3/h. The cleaning process inside an apartment is not for a long time, so, there is no need to oversize the ventilation equipment for a such airflow rate. Normal activities carried out inside an apartment are usually cooking in the kitchen, rest, study and similar domestic activities. For this type of activities, in the apartment it is necessary a ventilation system having an airflow rate 269 m^3/h of fresh air, to reach the allowed limit for air quality (carbon dioxide concentration of 1,000 ppm). If we want to achieve a higher air quality, with a carbon dioxide concentration of 600 ppm, we need a volumetric fresh airflow rate up to 866 m^3/h.

The results of this study take us to the conclusion that, if it is required a better air quality inside an apartment, it have to choose a ventilation equipment able to introduce larger quantities of fresh air, with higher energy consumption. This also leads to an increased level of energy for fresh air treatment (heating, cooling, etc.).

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1. 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, 1789-1794, DOI: 10.3303/CET1439299. 2. Žukovskij S. S., Voznyak O. T., Dovbuš O. M., Ljuľčak Z. S.: Ventilljuvannia primiščeň, Lviv, Vidavnictvo Nacionalnovo zniversiteta "Lvivska politechnika" 2007, p. 231–238, ISBN 978-966-553-645-1.3. 3. 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. 4. Voznyak O. T. Dynamichnyj mikroklimat ta energooshchadnist – Visnyk Nats. Un-tu "Lvivska politehnika" № 460 "Teploenergetyka. Inzhenerija dovkillia. Avtomatyzatsija", 2002 (in Ukrainian) – C. 150–153. 5. 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. 6. Persily A. 1997. Evaluating building IAQ and ventilation with indoor carbon dioxide. ASHRAE Transactions, Vol. 103. C. 193–204. 7. 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. 8. STN EN 13779, 2005, Slovakian Standard - European Norm, Ventilation for non-residential buildings. General requirements for ventilation and air conditioning equipment, 62 pages. 9. Doležílková H. 2007. Residential microenvironment. PhD thesis. Czech Technical University in Prague, Faculty of Civil Engineering. 2007.