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MONITORING OF INDOOR AIR IN THE APARTMENT

Мешканці квартири значно впливають на якість повітря в приміщенні. Повітря всередині приміщень забруднюється водяною парою, вуглекислим газом та іншими газами та тілесним запахами. Негативно впливають на якість повітря принесений одяг і взуття або виділення з підлог, килимів тощо. Наведено результати експериментальних вимірювань якості повітря в приміщеннях, переважно концентрації вуглекислого газу, температури повітря і відносної вологості. Внутрішні параметри повітря реєструються протягом 24 годин за кожен день весь тиждень. Вимірювання відбувалися в таких кімнатах: вітальні, дитячій кімнаті, кухні, ванній кімнаті та коридорі. В процесі вимірювань досліджувані приміщення були зайняті особами різної статі, віку і ваги. Виміри проводили, використовуючи комп'ютер, під час сидячої роботи та інших домашніх робіт. Основним результатом дослідження є моніторинг повітря у квартирі, розрахунок природної вентиляції приміщень внаслідок інфільтрації через будівельні конструкції. Отримані значення продуктивності природної вентиляції можна буде використовувати для визначення необхідної інтенсивності вентиляції для досягнення потрібної якості повітря. На підставі графічних ілюстрацій концентрації вуглекислого газу можна спостерігати реальну зміну концентрації вуглекислого газу в квартирах. За результатими вимірювань можна зробити висновок про перевищення допустимої концентрації забруднень у квартирі.

Ключові слова: якість внутрішнього повітря, двоокис вуглецю, температура, відносна вологість, квартира.

Apartment occupants have a major impact on indoor air quality. Indoor air pollution includes water vapour, carbon dioxide and other gases due to respiration and bodily odours. Negative impact they have from brought in by clothing and footwear or becomes whirled up from floors, carpets etc. In this article presents the experimental measurement of indoor air quality, mainly concentration of carbon dioxide, air temperature and relative humidity. Indoor air parameters are recorded during 24 hour per every day the all week. Measurements take place was exercised in these rooms: living room, children rooms, kitchen, bathroom and corridor. During the measurements the investigated room was occupied by different persons regarding the sex, age and weight. Measurements were carried out during a sedentary work using computer and other home works. The main result of this research is the monitoring of indoor air in the apartment for, calculation of uncontrolled ventilation of rooms, which is caused leaks through building structures. The resulting values, calculated of uncontrolled ventilation rate, it will be possible to use for in determining the needed ventilation rate for the achieving needed air quality. From The graphic illustrations concentration of carbon dioxide, is possible observe real course the concentration of carbon dioxide in the apartments during their use. From measurements is possible conclude, whether in the apartment, during its use, occur there the over limit values of pollutants.

Key words: indoor air quality, carbon dioxide, temperature, relative humidity, apartment.

Introduction. Because of environment protection reasons, the nowadays trend is to decrease as much as possible the energy consumption of buildings and thereby the reduction of air pollutants releases

into the atmosphere. One of the most important action is to reduce the fuel consumption during building operation, especially by decreasing its heat loss. For this purpose, the building envelope has better insulations and higher degrees of air tightness. The proper sealing of the building will reduce the uncontrolled natural ventilation by leakage, mainly through doors and windows. All these efforts will reduce the energy consumption of the building, but it will create an uncomfortable environment inside buildings, by the meaning that the living space will be not adequately ventilated. One of the negative consequences is the occurrence of fungi in apartments. The high energy costs, force the residents of apartments to enwrap the thermal insulation of building and also to seal the building. On the other side, it occurs a deterioration of indoor environment in buildings. In the article is presented the variation for some of the indoor air parameters such as: temperature, relative humidity and carbon dioxide concentration. The article is mainly aimed on monitoring the concentration of carbon dioxide, because is the main pollutant produced by the humans.

Material and methods. Assessed is three-room apartment, which is located in the eight storey block of flats in a housing estate, with a floor area of about 72 m^2. The building was build 35 years ago. In recent years, it have been replaced the old wooden windows with new plastic double glazing windows. The apartment is lived by two adults and two teenagers. Measurement were carried out in winter, in February. During measurements the family activities were carried out normally: the parents went to work during the day and children went to school.

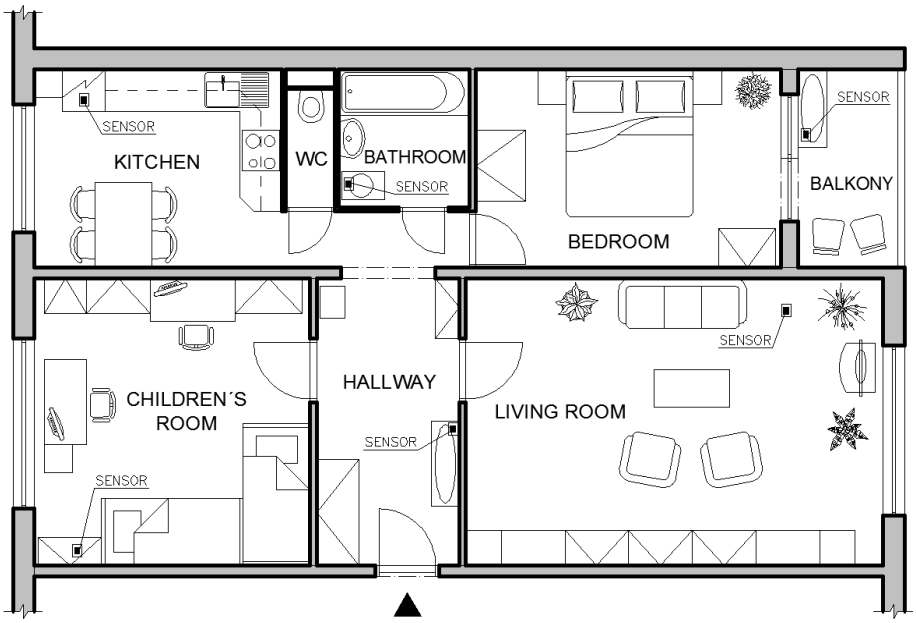

Fig. 1. The apartment plan

For each individual room of the apartment were recorded the main indoor air parameters: temperature, relative humidity and carbon dioxide concentration. For monitoring the indoor air parameters there were used a CO_2 sensor and a thermo-hygrometer. The principle of the measurement of CO_2 sensor C-AQ-0001R is based on the variation of infrared radiation depending on the carbon dioxide concentration. The carbon dioxide concentration measurement range is from 0 to 5000 ppm and the measurement accuracy is ± 75 ppm. The thermo-hygrometer S3541 is designed for recording air temperature and relative humidity. The measurement range of temperature is from -30 to + 70 ° C and the accuracy is ±0.4 °C. The measurement range of relative humidity is from 5 % to 95 % and the accuracy is ±2.5 % RH at 25 °C. The recorded values are stored to a non volatile electronic memory. During the measurements, the thermo-hygrometer was used concomitantly and interconnected with the sensor of carbon dioxide concentration. Both devices have a calibration certificate with declared metrological

requirements of standard STN EN ISO / IEC 17025. For downloading data into a computer, it was used the software Datalogger 2.240.0 developed by Comet System.

Measurement of indoor air parameters. The measurements were carried out separately for each apartment room. In each of them 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 the following figures are presented the measured parameters of indoor air in each apartment room.

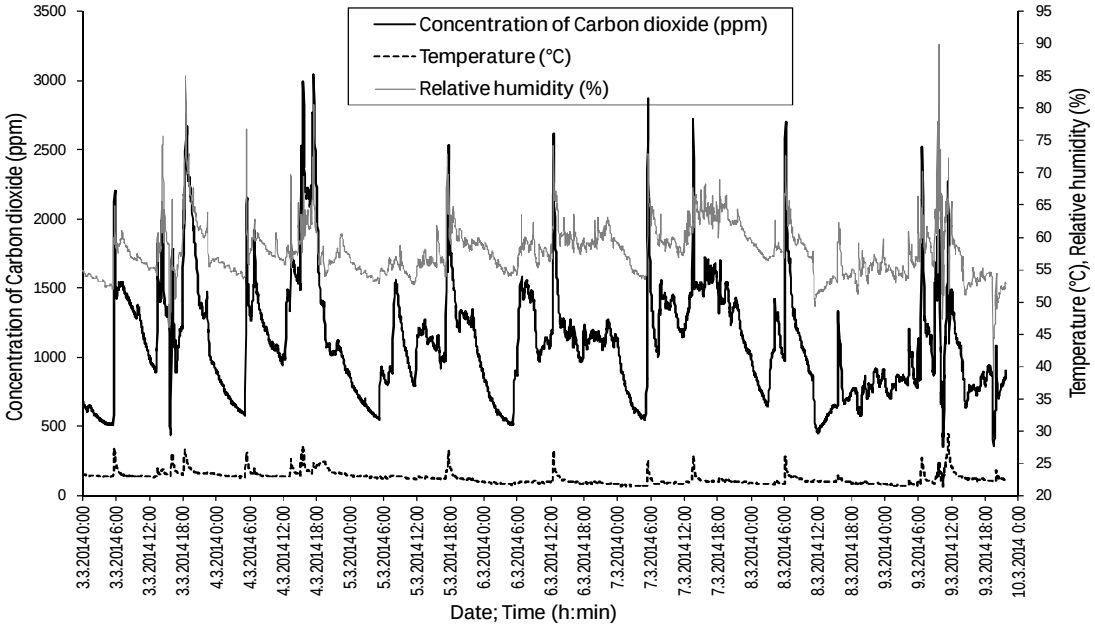

Fig. 2. Variation of indoor air parameters in kitchen

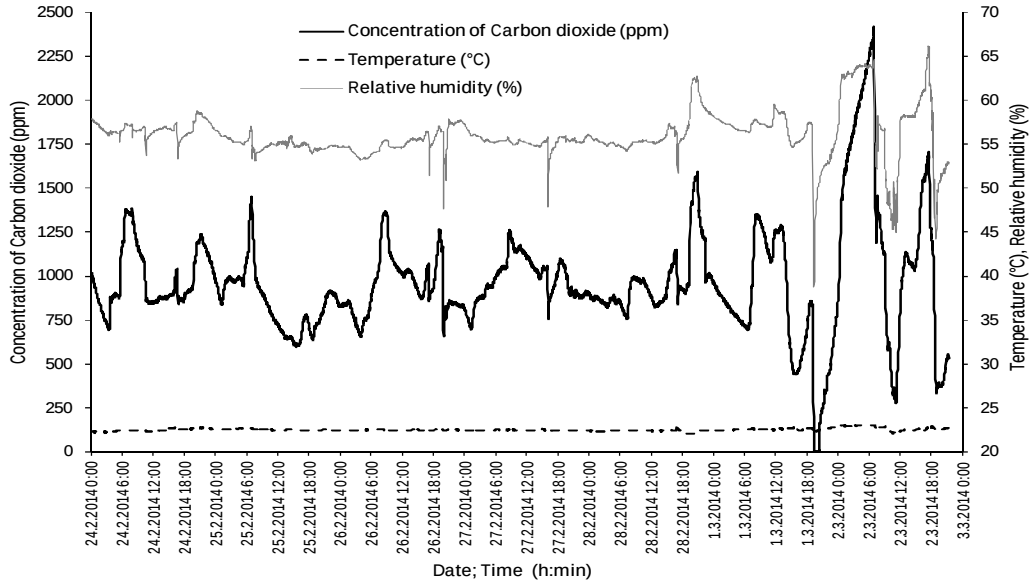

Fig. 3. Variation of indoor air parameters in living room

Similarly, there are recorded the indoor air parameters from other rooms in the apartment. From the fluctuation of measured values we can observe that the range of carbon dioxide concentration, air

temperature and relative humidity are approximately in the same intervals for any of surveyed room, but each individual room of the apartment has its own typical course.

In the next step, the investigation was focused only the carbon dioxide concentration. In order to obtain as accurately results as possible, the course of carbon dioxide concentration was drawn for each room. In this article is presented only the course of carbon dioxide concentration in the most representative chamber, namely the living room. It can be observed that, during the whole week the carbon dioxide concentration course is approximately the same except Sunday because in that day the living room was used as a bedroom for two adult guests. Sunday's course of carbon dioxide concentration is similar in living room with the one from bedroom.

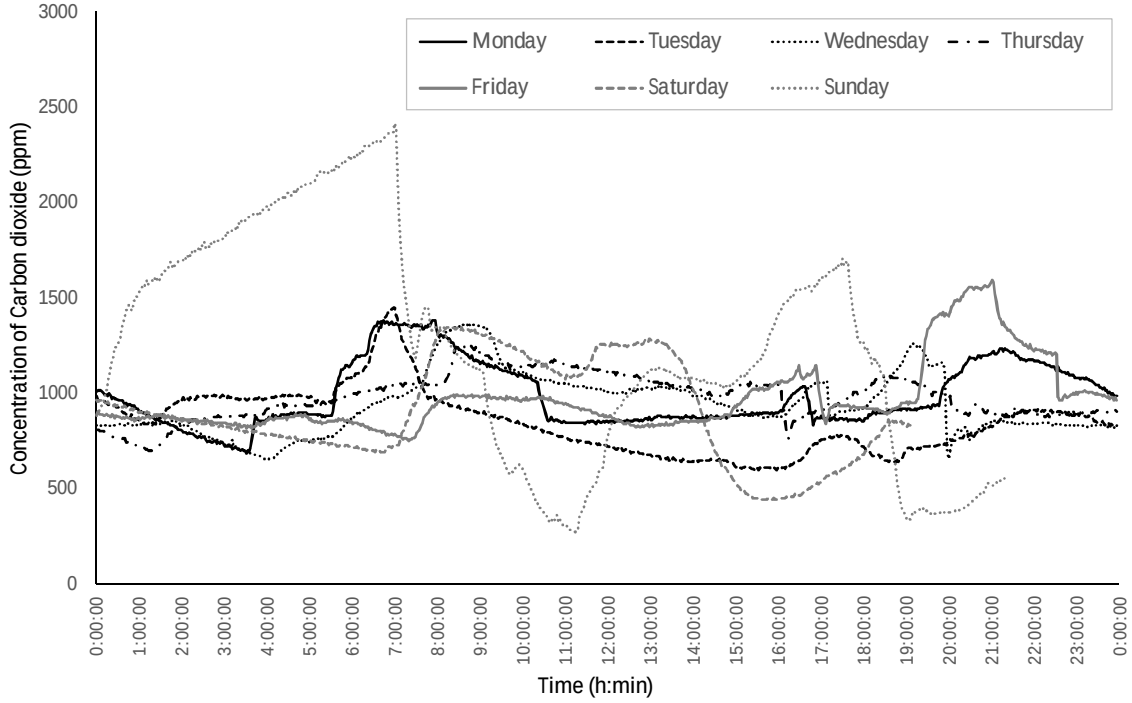

Fig. 4. Daily measurement of carbon dioxide concentration in the living room

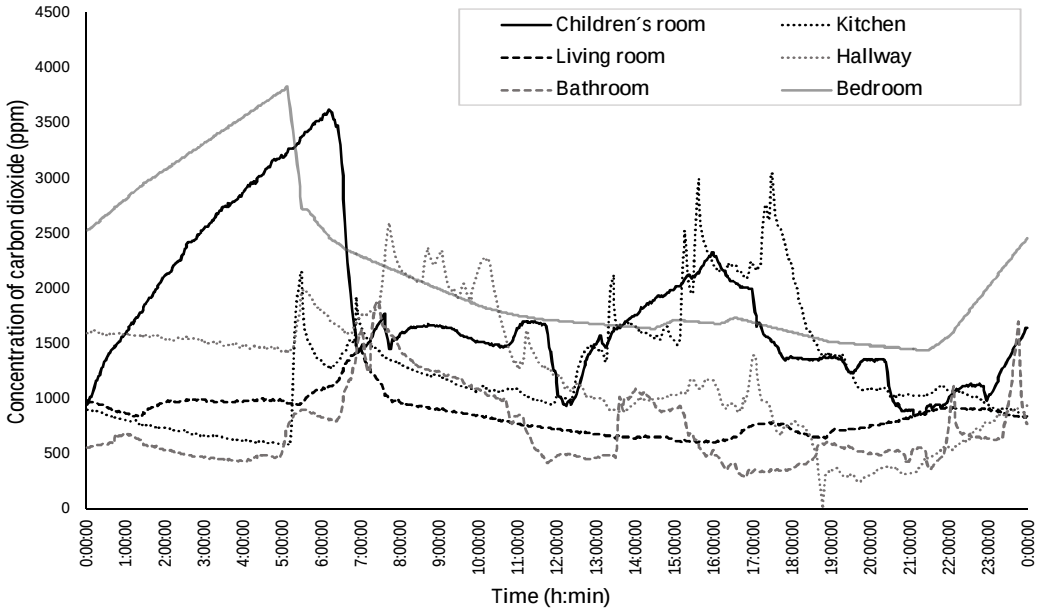

Fig. 5. Tuesday measurement of carbon dioxide concentration in all the rooms

Calculation of the uncontrolled ventilation rate. From measured values of carbon dioxide concentration, it can be calculated the ventilation rate caused by infiltration. For determining the air exchange rate by infiltration in apartment rooms it is used the indirect chemical mixing method, which is based on monitoring the decreases of air pollutants concentration in time, in our case the carbon dioxide concentration, assuming that is no occupant in the room. The measurement will end when carbon dioxide concentration in the room is approximate the same with outdoors carbon dioxide concentration.

In our case, the carbon dioxide was produced by humans and that is why the CO_2 concentration is increased. When the room is empty, it can be considered that carbon dioxide production is zero. In this period of time can be observed that carbon dioxide concentration decreases gradually, which is caused by the uncontrolled natural ventilation through infiltration.

Because carbon dioxide concentration at the end of measurements was different compared with carbon dioxide concentration from outdoor, the natural ventilation rate through infiltration in the surveyed room can be determined from the decreases of carbon dioxide concentration in time [6, 7].

$$\frac{C_{IDA,B} - C_{SUP}}{C_{IDA,C} - C_{SUP}} = e^{-n.t} \quad (1)$$

where: n - ventilation rate by infiltration [1/s]; $C_{IDA,B}$ – carbon dioxide concentration at the beginning of CO_2 concentration decrease [mg/m^3]; $C_{IDA,C}$ – carbon dioxide concentration at the end of CO_2 concentration decrease [mg/m^3]; C_{SUP} – outdoor carbon dioxide concentration [mg/m^3]; t – time of CO_2 concentration decrease [s].

It results the final formula for the natural ventilation rate through infiltration:

$$n = \frac{1}{t} \cdot \frac{\ln(C_{IDA,B} - C_{SUP})}{C_{IDA,C} - C_{SUP}} \quad (1/s) \quad (2)$$

As an observation, during CO_2 concentration decrease, the boundary conditions (outdoor air temperature and wind speed) were changed and that is why the intensity of infiltration is influenced. In this order, the natural ventilation rate through infiltration must be determined by using the measured carbon dioxide concentrations values. The resulting values of intensity of ventilation are given in Table 1.

Table 1

The calculated values of the intensity of ventilation

Type of room	Volume of room	Number of persons	Time of measurement	Concentration of carbon dioxide			Ventilation rate
				Outdoor air	At the start	At the end	
	[m^3]	[-]	[s]	[mg/m^3]	[mg/m^3]	[mg/m^3]	[1/h]
Hallway	27	2	2160	755	3315	2772	0,40
Living room	62	2	1440	755	2272	2138	0,23
Children´s room	41	2	1140	755	323	3146	0,11
Kitchen	25	2	1560	755	2941	2561	0,44
Bathroom	8	1	840	755	2820	2583	0,52

From the calculated values of the intensity of natural ventilation it can be concluded that, not in every room is the same ventilation rate through infiltration. In bathroom and kitchen there are installed exhaust fans, which increase the uncontrolled ventilation, and, even if it does not work, the natural ventilation is present through the vertical exhaust canal. In the hallway there are no windows, but there are entrance doors, which induce a small natural ventilation rate (chimney effect), because the apartment is located at the 8th floor.

Discussion. By analyzing the resulted values of uncontrolled ventilation rate caused by leakages through building structures, which are calculated on the basis of carbon dioxide concentration measurements, it can be concluded that each room has a different intensity of ventilation. A great influence on the final value, have the number of occupants and the time they stay in every measured room. Not in every room the door were closed during measurement. Also, a big impact on increased intensity of

uncontrolled ventilation has the chimney effect because the analyzed apartment is on the 8th floor of the apartment building. We suppose that, in winter, through entrance door comes in air from the staircase area and after that is towed out from the apartment, over the roof of the building, through natural ventilation canal from kitchen and bathroom. Therefore, is certain that in hallway, bathroom and kitchen there is an increased uncontrolled air exchange.

In living room it is calculated a double uncontrolled air exchange caused by the manner of using the room. We assume that the door remained open also during the absence of people, because it is a room available for all household members.

In the children's room is the lowest uncontrolled air exchange caused by infiltration building elements. When the room was empty, the door to hallway was closed. The calculated ventilation rate corresponding to real values of air infiltration through window if the room door and window were correctly closed.

Conclusions. From the indoor air parameters measurements it can be concluded that, during the winter, when windows were most of the time closed and it was no mechanical ventilation in the apartment, it were recorded increased concentrations of carbon dioxide. According to EN 13779 (2005), the acceptable limit is a level of 1,000 ppm. In the investigated the apartment occurred over limit values of pollutants (carbon dioxide). In the kitchen, bathroom and hallway took place short and steep increases and decreases of carbon dioxide concentration. In rooms where people have a longer stays: children's room, bedroom and living room, concentration increased slowly, but for passing the limit it takes a long time.

The ventilation rate caused by uncontrolled ventilation through infiltration calculated with equation (2) may be use for each individual room. The research presented in this paper is important for proper designing of ventilation system in apartments. The measured values of carbon dioxide concentration and calculated rates of uncontrolled ventilation caused by infiltration through building elements may be used for calculating the mass flow rate of carbon dioxide and subsequently, for determining the volume needed fresh airflow rate inside apartment rooms, in order to ensure a healthy indoor environment.

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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, 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.