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# VENTILATION AND INDOOR AIR QUALITY IN THE CLASSROOM



**Звернено увагу на важливість охорони навколишнього середовища щодо скорочення споживання енергії за збереження рівня життя. У низькоенергетичних будинках до 80 % від загального тепла споживається для опалення та вентиляції. Метою цієї статті є вивчення впливу температури, вологості, швидкості руху повітря і концентрації вуглекислого газу на поведінку людини в приміщенні з природною вентиляцією.**

**Ключові слова: концентрація вуглекислого газу, вентиляції, потік.**

**This paper highlights the importance of environmental protection regarding the reduction of energy consumption while keeping the living standard. In low energy houses, up to 80 % of the total heat is consumed for the heating of fresh air for a comfortable environment. The aim of this article is to examine the effect of temperature, humidity, air velocity and concentration of carbon dioxide in regard to the human behaviour in indoor environment with natural ventilation, i.e. without a ventilation device, where ventilation is forced or an air conditioning.**

**Key words: concentration of carbon dioxide, ventilation, flow.**

## Introduction

By improving thermal properties and 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 and passive houses about 80 % of total energy consumed for heating is used to heat the fresh air needed for occupants.

According to studies [1], [2] actual houses usually have larger floor areas, whereas the number of persons living in the house is reduced. This means a larger floor area per person and due this fact also consumption of the fresh air per square meter in the given house is reduced. Such a fact is very important with regard to the evaluation of rooms according to temperature, concentration of carbon dioxide and relative air humidity [3].

### Production of carbon dioxide

The people that are in the room inhale air. Carbon dioxide and other gases are in the exhaled air. In the outdoor air about 400 ppm of carbon dioxide can be typically measured. When the carbon dioxide concentration reaches 1000 to 1500 ppm, undesirable feelings occur in persons Higher concentrations are very undesirable – see table 1.

*Table 1*

**The effect of increased $CO_2$ concentrations on the human body** 0

| Concentrations of $CO_2$ (ppm) | The effect on the body |
|---|---|
| 330–400 | Outdoor air – fresh air |
| 450–1000 | The pleasant feeling – good level |
| 1 000–2000 | Sleepiness – bad air |
| 2000–5000 | Possible headaches |

Experimental measurements were carried out in a classroom where several people carried out work in a seated position. We calculated mass flows of CO2 expecting an average inhale / exhale with a capacity of 0,5 litre and the intensity of respiration between 10 and 18 breaths per minute. Calculated values of the mass flow for various intensities of respiration (10 to 18 per minute) with the volume of one inhale / exhale 0.5 litres are presented in table 2.

*Table 2*

**Calculated values of mass flow of CO2 with expected inhale / exhale volume of 0.5 l**

| Intensity of respiration (1/min) | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|---|---|---|---|---|---|---|---|---|---|
| Mass flow of $CO_2$ (mg/s) | 6,55 | 7,20 | 7,86 | 8,51 | 9,17 | 9,82 | 10,47 | 11,13 | 11,78 |

The assessed classroom is located on the fifth floor of a five storey building. During the period of measurement the number of people present in the room varied. The dimensions of the classroom are: length 10,92 m, width 5,63 m and height 1,94–4,10 m. In the external wall five windows are built-in. Dimensions of those windows are: width 0,74 m and height 0,76 m. There are ten windows built-in in the roof deck. Dimensions of roof windows are: width 0,7 m and height 1,1 m. The internal volume of the room is 199 $m^3$. The floor area of the room is 65 $m^2$.

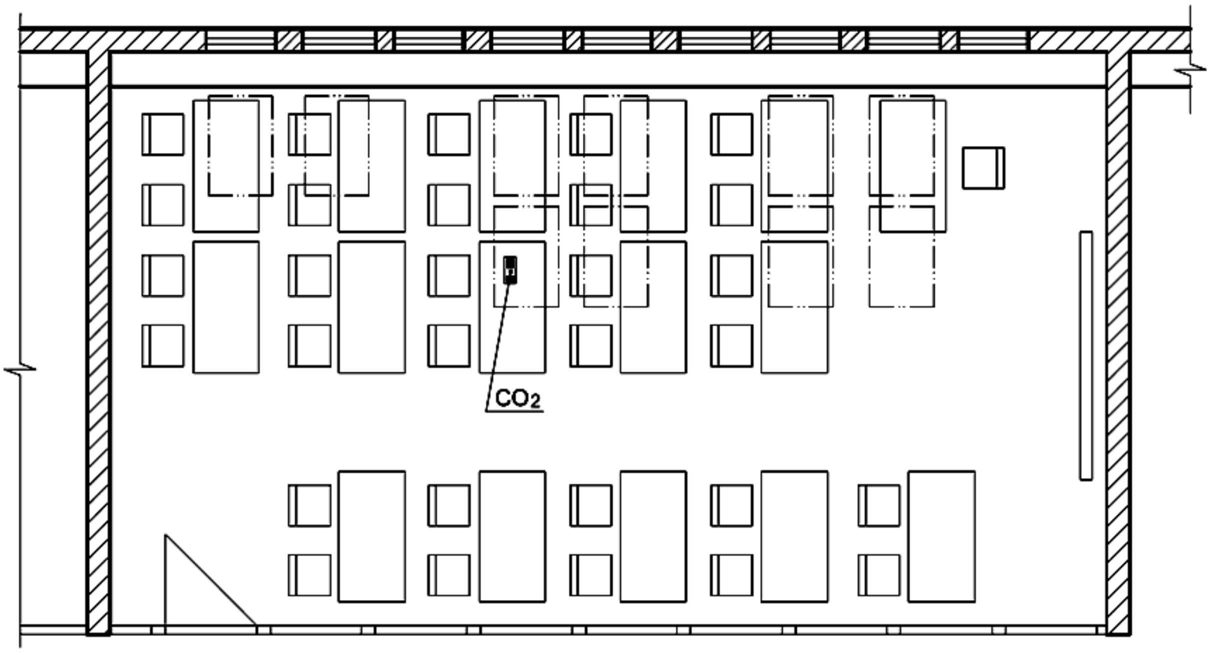


*Fig. 1. Measured classroom*

*Table 3*

**Characteristic data of measurements**

| Number of measurement | Date of measurement | Number of women (–) | Number of men (–) | Mass of persons (kg/per) | People age (years/per) | Area per person ($m^2$/per) |
|---|---|---|---|---|---|---|
| 1 | 01/07/2014 | 5 | 12 | 69 | 23 | 3,5 |
| 2 | 01/09/2014 | 2 | 2 | 75 | 24 | 15,0 |
| 3 | 01/14/2014 | 2 | 7 | 75 | 23 | 6,7 |
| 4 | 01/16/2014 | 6 | 11 | 67 | 23 | 3,5 |
| 5 | 01/20/2014 | 4 | 12 | 70 | 23 | 3,8 |
| 6 | 01/23/2014 | 1 | 6 | 82 | 23 | 8,6 |
| 7 | 01/24/2014 | 1 | 7 | 83 | 28 | 7,5 |
| 8 | 01/24/2014 | 1 | 7 | 83 | 28 | 7,5 |

During the presence of persons in the room our measuring devices recorded indoor air temperature, indoor air humidity and concentration of carbon dioxide. Characteristic data of measurements in this room are documented in table 3 and in table 4.

The number of persons present in the room during each measurement is variable. Every person, who was is in the room, expressed their feelings by filling out a questionnaire.

After finishing work persons completed a questionnaire, in which they indicated their perception on the room temperature and perception on the odor and smell. Results of subjective opinions on the quality of indoor environment are processed in table 5.

*Table 4*

**Measurement of the air parameters**

| Number of measurement | Number of people (–) | Length of stay (min) | Average temperature in the room (°C) | Average air humidity (%) | Maximum concentration of $CO_2$ (ppm) |
|---|---|---|---|---|---|
| 1 | 17 | 65 | 21 | 40 | 1 685 |
| 2 | 4 | 70 | 21 | 51 | 809 |
| 3 | 9 | 95 | 22.7 | 29 | 1 546 |
| 4 | 17 | 90 | 22.8 | 33.5 | 1 707 |
| 5 | 16 | 90 | 22.9 | 43.3 | 2 141 |
| 6 | 7 | 106 | 24.5 | 25 | 1 017 |
| 7 | 8 | 240 | 26.8 | 23 | 1 566 |
| 8 | 8 | 165 | 28.2 | 23 | 1 347 |

*Table 5*

**Perceived indoor air quality**

| Number of measurement | Perceive the air temperature Number of people (%) | | | Perceive the scent intensity Number of people (%) | | |
|---|---|---|---|---|---|---|
| | Clearly acceptable | Just acceptable | Just unacceptable | None | Weak | Moderate |
| 1 | 59 | 41 | 0 | 53 | 35 | 12 |
| 2 | 0 | 100 | 0 | 0 | 75 | 25 |
| 3 | 67 | 33 | 0 | 0 | 44 | 56 |
| 4 | 53 | 47 | 0 | 29 | 53 | 18 |
| 5 | 81 | 19 | 0 | 50 | 37 | 13 |
| 6 | 71 | 29 | 0 | 86 | 0 | 14 |
| 7 | 13 | 63 | 24 | 63 | 25 | 12 |
| 8 | 13 | 38 | 49 | 13 | 63 | 24 |

Impact of temperature on the people (in the room) according to the questionnaires elaborated in fig. 3. Individual measurements are evaluated by the effect of temperature (number from 1 to 8) and sorted by temperature in the charts – see fig. 2. The order of measurements is: 1, 2, 3, 4, 5, 6, 7 and 8. People reacted to the indoor air temperature accurately.

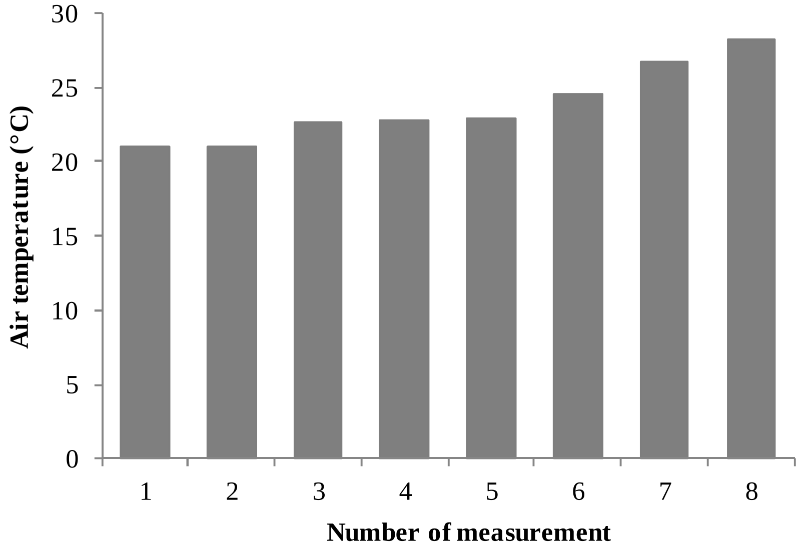


*Fig. 2. Indoor air temperature*

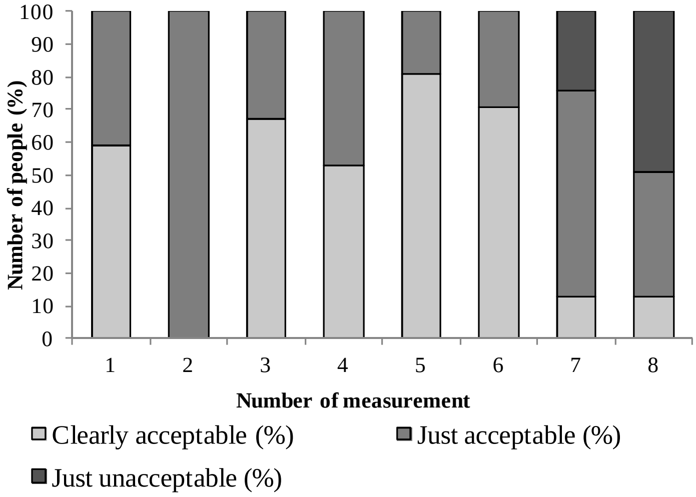


*Fig. 3. Impact of temperature on the people*

From fig. 3 it can be seen that people reacted to the indoor air temperature accurately. When the temperature in a room is increased, so the number of dissatisfied persons increases.

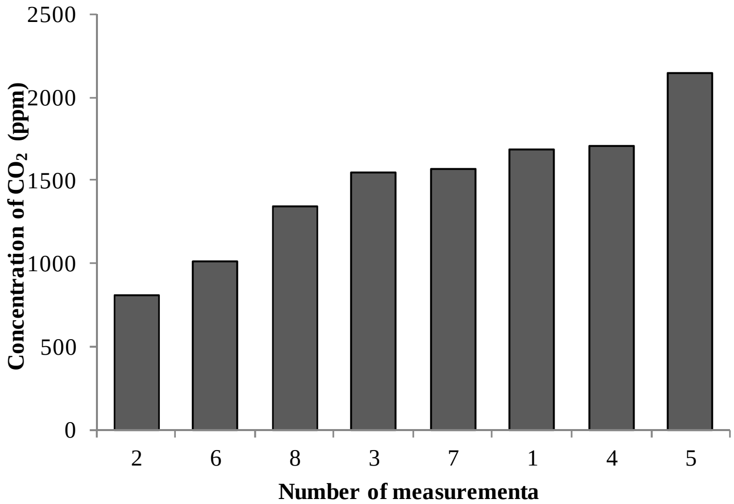


*Fig. 4. Maximum concentration of $CO_2$*

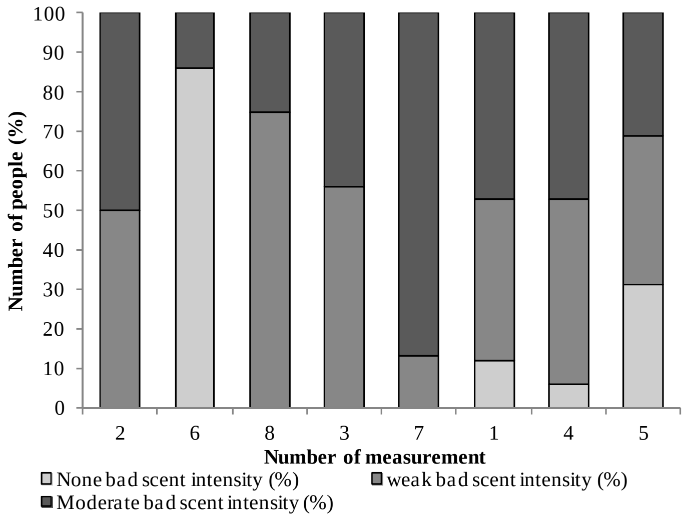


*Fig. 5. Impact of concentration of carbon dioxide on the people*

Impact of concentration of carbon dioxide can be evaluated directly proportional with odor. Individual measurements are evaluated by the effect of odor intensity (number from 1 to 8) and sorted by the concentration of carbon dioxide in the charts. The order of measurements is: 2, 6, 8, 3, 7, 1, 4 and 5 (see fig. 4). The impact of concentration of carbon dioxide according to the questionnaires is elaborated in fig. 5. From figure 6 is can be concluded, that people reacted to bad scent intensity less accurately. When the CO2 concentration in room is increased, people are little responsive to bad scent.

## Conclusion

During the experiment, the studied classroom was occupied with persons who produced 9,82 mg/s of carbon dioxide, based on measurement results.

From the questionnaires we can conclude that people react to temperature changes in a room more accurately than to changes in odor caused by the changes of $CO_2$ concentration. Increasing $CO_2$ concentration is hardly perceived by persons, especially when they constantly inside the room and focused on a particular task. His performance deteriorates uncontrollably and tiredness occurs sooner than usual. This is caused by the person's acclimation to the deteriorating environment. Persons only react to the changing air quality after a critical level is surpassed, which is individual for every person. With increasing $CO_2$ concentration slower reactions to proposed tasks can be expected.

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*1. EuroACE, Towards Energy Efficient Buildings in Europe, final report June, 2004. 2. Vaňo B., Jurčová D., Mészáros J. 2002. Prognosis of development population in Slovakia by the year 2050. Institute of informatics and statistics. Bratislava, 11.2002, Acts. 3. Porhincak M., Estokova A., Paulikova A. 2012. Environmental analysis of partition walls in terms of embodied carbon, sulphur dioxide and energy consuption . In: WateEng12 : 4th International Conference on Engineering for Waste and Biomass Valorisation : proceedings : Vol. 5 : September 10–13, 2012, Porto, Portugal. – Prifysgol : Swansea University, 2012. – P. 1545–1550. – ISBN 979-10-91526-00-5. 4. Gebauer G., Rubínová O., Horká H. Ventilation Technic. 2005. ERA group, spol. s.r.o., Brno. ISBN 80-7366-027-X. 5. Persily A. 1997. Evaluating building IAQ and ventilation with indoor carbon dioxide. Transactions American society of heating refrigerating and air conditioning engineers, 1997. – P. 193–204, ASHRAE. 6. Doležílková H. 2007. Residential microenvironment. PhD thesis. Czech Technical University in Prague, Faculty of Civil Engineering. 2007. 8. STN EN 13 779:2007 Ventilation in non-residential buildings. General requirements for ventilation and air conditioning equipments. 9. STN EN 15251:2007 Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. 10. Ventilljuvannia primiščeň / S. S. Žukovskij, O. T. Voznjak, O. M. Dovbuš, Z. S. Ljuľčak. – Lviv : Vidavnictvo Nacionalnovo universiteta „Lvivska politechnika“ 2007, ISBN 978-966-553-645-1, str. 45–47. 5. STN 730540: 2002, Thermal performance of buildings and constructions. 11. Nagy R., Košičanová D. 2012. Indoor Envirinment, Air Quality, Ventilation Rates – Numerical CFD Simulations, Calculations and Measuring Apparatus Applications In: Czasopismo Techniczne. – 2012. – Vol. 109, № 3. – P. 281–295. – ISSN 0011-456.*