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Section: Energy for Buildings

Effect of ventilation on indoor environmental quality in buildings

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Abstract

Living standard of people is increasing significantly recently and due to this fact energy requirements are also increasing. At the Technical University in Kosice a research examining the quality of indoor environment is carried out. There exists a constructed research centre, where an experimental house with passive standards in terms of building structures is designed. Heating and ventilation can be modelled in the house. Equipment is designed on the basis of calculated balances for the needs of heat, hot water demand and the need for ventilation of the building.
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 CO_2 concentration 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.

Keywords: ventilation; airflow rate; legislative; carbon dioxide (CO_2), concentration.

Nomenclature

Abbreviations

CO_2	carbon dioxide
IDA	category of indoor air
C-AQ-0001R	sensor unit for CO_2
S-3541	thermo-hydrometer

1. Introduction

Buildings with a low-level of energy consumption are trendy in Slovakia. In certain areas approx. 40% of total energy consumption is spent just for heating buildings. The following statistical data are known according to the EuroACE [1]: 57% of global energy consumption in a building is spent for heating, 25% for heating domestic hot water, 11% for lighting and electric appliances and 7% for cooking.

According to studies [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].

The faculty of Civil Engineering in Kosice is performing research on indoor air quality. The experimental house is designed in passive standards in terms of building structures. The experimental house (Fig. 1) is located in a space, where outdoor temperature and relative humidity can be simulated.

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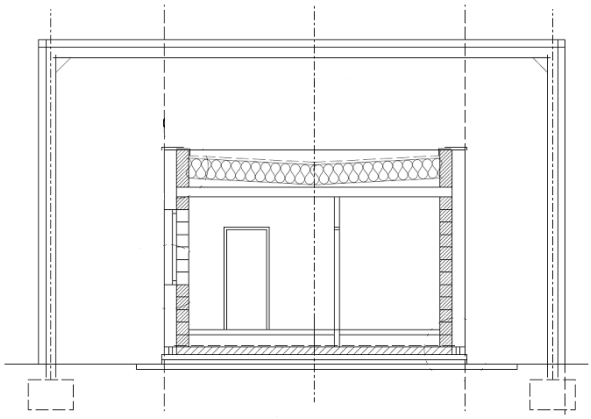

Fig. 1. Cross section of the experimental building

2. Research Methods

2.1. 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 [4], [5]. Higher concentrations are very undesirable – see Table 1.

Table 1. The effect of increased CO_2 concentrations on the human body [6]

Concentrations of CO2 (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,
over 5000	Discomfort, rapid heart rate
over 15000	Problems with breathing
over 30000	Dizziness and indisposition
over 60000	Blackout

Exhaled air contains 3.6 – 4.2% of CO_2 [7]. Experimental measurements were carried out in a classroom where several people carried out work in a seated position. We calculated mass flows of CO_2 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 CO_2 with expected inhale / exhale volume of 0.5 litre

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

From the data of CO_2 concentration obtained by measurements carried out when people stayed in the classroom and from the calculated ventilation rate by infiltration we determined the value of mass flow of CO_2. The discovered actual production of CO_2 was 8.1 mg/s per person.

2.2. Indoor air quality

For indoor air quality in Slovakia European standards STN EN 13 779 [8] and STN EN 15215 [9] are valid, which characterize the four degrees for air quality: IDA 1 till IDA 4. The degrees of quality of indoor air are further described in Table 3.

Table 3. Indoor air quality

Cat.	Quality of indoor air	Cat.	Qualitative description of indoor air
according to STN EN 13779 [8]		according to STN EN 15251 [9]	
IDA 1	High	I.	High indoor air quality for hospitals and the like.
IDA 2	Medium	II.	Standard level for new and reconstructed buildings.
IDA 3	Moderate	III.	Acceptable level for existing buildings
IDA 4	Low	IV.	Only limited acceptable level

In our experimental house we required air quality IDA 2, where a maximum CO_2 concentration of 1000 ppm is allowed.

2.3. Experimental measurement of air parameters

In order to determine the values of carbon dioxide concentration a CO_2 sensor unit C-AQ-0001R (Fig. 2a) was used. To measure the air temperature and relative humidity we used a thermo-hydrometer measuring device S-3541 (Fig. 2b).

(a) (b)

Fig. 2. Measuring device: (a) CO_2 concentration sensor unit C-AQ-0001R (b) Thermo-hydrometer measuring device S-3541

Several experimental measurements were carried out. Measurements were carried out in winter on different days in the room – see Figure 3.

Fig. 3. Measured room

The assessed room 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. The internal volume of the room is 199 m^3. The floor area of the room is 65 m^2.

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 4.

Table 4. 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

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 – see Figure 4.

Age: ..... years Weight: ..... kg	Date of evaluation: ..... Hour: ..... Total time spent in the indoor environment: ..... hours ..... minutes
Sex:	Number of minutes spent in the indoor environment from the start of filling up the questionnaire: ..... minutes
☐ male ☐ female	

How do you rate your thermal sensation?	How do you perceive the temperature?	Do you want the room temperature?
☐ Hot ☐ Warm ☐ Slightly warm ☐ Neutral ☐ Slightly cool ☐ Cool ☐ Cold	1 Clearly acceptable 0 Just acceptable 0 Just unacceptable -1 Clearly unacceptable	☐ Higher ☐ No change ☐ Lower
How do you perceive the bad smell intensity?	**How do you perceive the scent intensity?**	**How do you perceive the air quality**
☐ None ☐ Weak ☐ Moderate ☐ Strong ☐ Very strong ☐ Overpowering	☐ None ☐ Weak ☐ Moderate ☐ Strong ☐ Very strong ☐ Overpowering	1 Clearly acceptable 0 Just acceptable 0 Just unacceptable -1 Clearly unacceptable

Fig. 4. Questionnaire for the subjective evaluation the indoor environment

The evaluation of measurements and subjective evaluation of the indoor environment are processed in the following chapter (see 3. Results and discussion).

3. Results and discussion

3.1. Measurement of air parameters

A total of eight measurements were carried in the classroom during examinations, when students elaborated answers to a given set of questions. After the written examination all students left the classroom, which remained empty and locked with closed windows. The CO_2 concentration in the classroom decreased in this period due to air infiltration from leaky windows. In Figure 5 the course of CO_2 concentration for the total length of stay of people in the classroom can be seen. Figure 5 shows the measured air parameters (CO_2 concentration, indoor air temperature and relative humidity) depending on time.

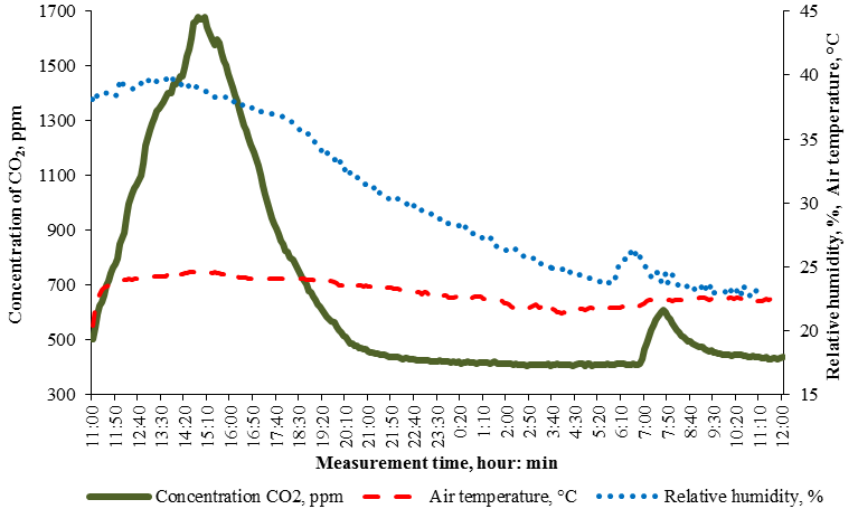

Fig. 5. Measured values of indoor air temperature, concentration of carbon dioxide and relative humidity

Experimental results for all measurements are presented in the Table 5.

Table 5. Measured 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	1685
2	4	70	21	51	809
3	9	95	22.7	29	1546
4	17	90	22.8	33.5	1707
5	16	90	22.9	43.3	2141
6	7	106	24.5	25	1017
7	8	240	26.8	23	1566
8	8	165	28.2	23	1347

The data specified in Tables 4 and 5 indicate a direct correlation of CO_2 concentration and the weight of people. It can be concluded, that people with higher weight produce more carbon dioxide than lighter people.

3.2. Indoor air quality

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 6.

Table 6. 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 Figure 6. Individual measurements are evaluated by the effect of temperature (number from 1 to 8) and sorted by temperature in the charts – see Figure 6. The order of measurements is: 1, 2, 3, 4, 5, 6, 7 and 8. People reacted to the indoor air temperature accurately.

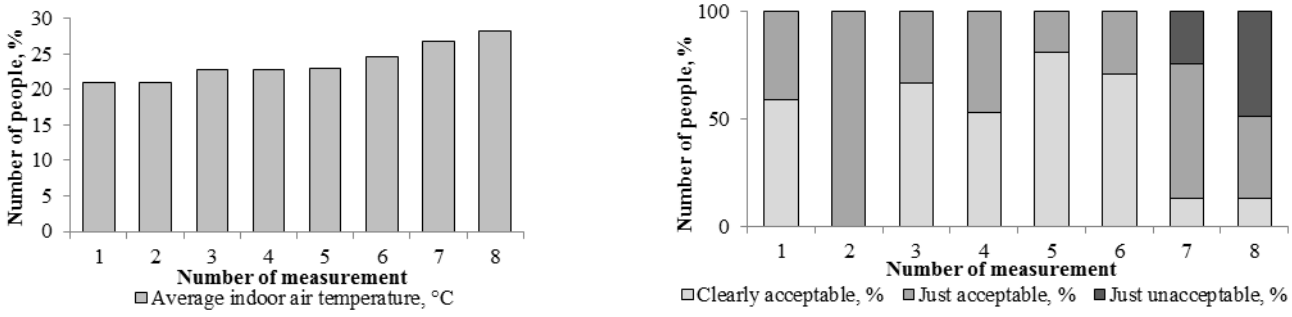

Fig. 6. Impact of temperature on the people

From Figure 6 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.

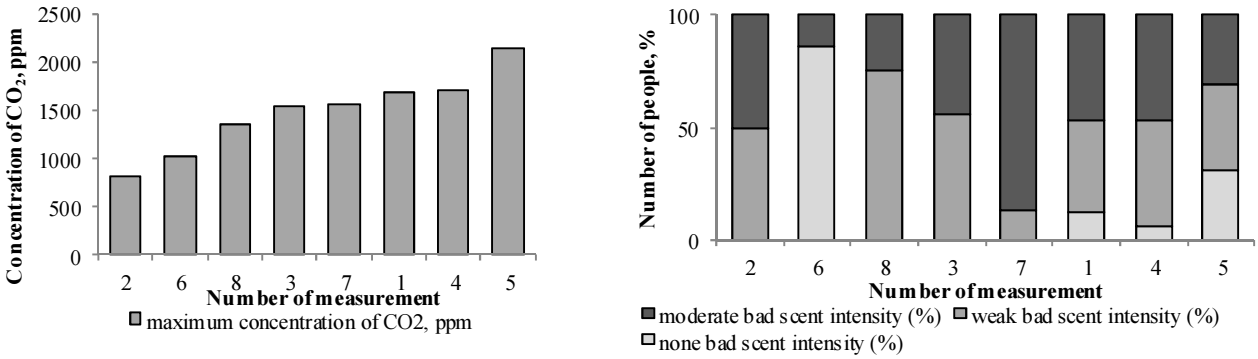

Fig. 7. Impact of concentration of carbon dioxide on the people

Impact of concentration of carbon dioxide can be evaluated directly proportional with odor. The impact of concentration of carbon dioxide according to the questionnaires is elaborated in Figure 7. 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.

From Figure 7 is can be concluded, that people reacted to bad scent intensity less accurately. When the CO_2 concentration in room is increased, people are little responsive to bad scent.

4. Conclusions

On the basis of our research it can be stated that heavier people produce more CO_2 than people with less weight. During future continuations of this line of research it will be interesting to investigate the correlation between a weight of person and CO_2 production more closely.

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 persons' 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. The effect of insufficient ventilation on a person's performance will be investigated in more detail in our future research.

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