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Carbon Dioxide Concentration in the Bedroom for Various Natural Ventilation Modes

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Abstract. The concentration of carbon dioxide (CO_2), respectively healthy and suitable hygienic indoor environment, is one of the current issues. Residence rooms, excluding rooms in family-run facilities and accommodation units, should be ventilated to comply with a maximum permissible carbon dioxide concentration of 1500 ppm during the stay of people. Many researches have shown that the indoor environmental quality has a significant effect on the incidence of health problems (Sick Building Syndrome, SBS). Nowadays, there are a number of grant programs to support energy-saving buildings, which resulted in massive thermal insulation of all types of buildings. Buildings are nearly airtight closed to reduce the energy losses, and the owners, under the vision of energy and financial savings, almost do not open the windows. It is quite certain that these buildings are inadequate in terms of air quality. The exception is where the air-conditioning units are installed. The experiment measuring the concentration of carbon dioxide in the bedroom is executed in March within a week. Measuring in the winter months is crucial for the evaluation of results because it is difficult to set up an ideal regime for natural ventilation during the winter. The supply of fresh air is achieved by natural ventilation by tilting window but the result is a low temperature (cold) in the interior. The experiment is carried out in a three-room apartment in České Budějovice with newly installed plastic till & turn windows with insulating double glazing. Window wings also allow opening of the tilting position (tilt) and micro-ventilation. The observed bedroom has a floor area of 14.5 m^2. Two adults live in the apartment. The concentrations of carbon dioxide overnight are assessed under different modes of natural ventilation by tilt & turn window combined with open interior doors to other rooms. The results show a significant effect of ventilation on the air quality. Data proves that only natural ventilation through the new tight windows in renovated apartment buildings is inadequate.

1. Introduction

Air pollution becomes the biggest environmental risk to the health. Furthermore, on average, people spend up to 90% of their time indoors; hence, the indoor environment has a significant impact on human health, productivity, and emotional state. During the day people are in the office or school, in the evening and at night they are at home in an apartment or in a family house. People sleep approximately 8 hours a day. Sleep is an important activity for people. People spend almost one-third of their lifetime sleeping [1]. Most people do not think about the interior of buildings where they spend most of their time. Many factors, such as lighting, acoustics, or rather noise, temperature and airflow, air quality (carbon concentration), humidity, the presence of green, etc., affect the indoor environment. The indoor environment should be as natural as possible. Many researches have shown that a healthy indoor environment has a significant share of morbidity [2-8]. Ensuring the high-quality indoor environment, well-being and health of occupants are one of the key tasks according to the basic principles of sustainable construction of buildings. The synergistic action of the individual components of the microclimate is an important determinant of the quality of the indoor environment [9]. Environmental quality of the indoor environment is the conceptual system principle of architectural, constructional and environmental design development [10].

The concentration of carbon dioxide (CO_2) plays an essential role in indoor air quality (IAQ). Carbon Dioxide is the most common air contaminant, whose concentrations are always higher in the interior than in the outdoor environment. Carbon dioxide concentration, respective a healthy and hygienic indoor environment is one of the topical issues. Residential rooms, except for rooms in family recreation buildings and accommodation units, must be ventilated in such a way that the maximum permissible concentration of carbon dioxide of 1500 ppm is maintained during the stay users. The source of CO_2 is primarily human and its activities, through metabolism, breathing and thermoregulation. According to the activity, the amount of CO_2 produced per person is between 10 and 75 liters per hour. The number of people in the room, the frequency of ventilation and the size of the area (air volume) have a major impact on increasing the concentration in the indoor environment. Another source of CO_2 is the burning of solid fuels. As the concentration of carbon dioxide increases, the amount of water vapor in the air increases and the relative humidity of the air increases. In particular, breathing is adversely affected by higher CO_2 concentrations. Carbon dioxide concentration has a strong correlation with human odors. High concentrations can cause headaches, dizziness and nausea. According to the World Health Organization (WHO), today about 85% population show symptoms of sick building syndrome (SBS). The symptoms of SBS can be described as a group of more or less serious diseases and health problems that occur during a long stay in closed rooms.

Nowadays, when subsidies support energy savings of buildings, all types of buildings are insulated. Economic factors significantly affect indoor air quality [11]. Airtightness can be defined as air leakage through the external building envelope. The air leakage of the building is characterized by the out-of-control exchange of air by leaks in the external cladding where such leaks negatively influence the energy balance of the building [12]. Buildings have been almost airtight in order to reduce energy losses and almost do not open windows under the prospect of savings. It is almost certain that these buildings are inadequate in terms of air quality. The exception is where the air-conditioning units are installed.

2. Method of experiment

The measurement of carbon dioxide concentration in the bedroom was carried out in March 2019. The measurement took place within one week. Measurements during the winter months are crucial for the evaluation of the results because in winter it is difficult to achieve an optimal regime in natural ventilation. The open tilt and turn windows provide fresh air but at the expense of cold indoor temperatures.

The experiment is carried out in a three-room apartment in České Budějovice with newly installed plastic till & turn windows with insulating double glazing. Window wings also allow opening of the tilting position (tilt) and micro-ventilation. The window has a dimension of 750 x 2570 mm. In the case of interior doors without a threshold, slight infiltration from other parts of the apartment can be assumed. The observed bedroom has a floor area of 14.5 m^2. The room volume is 37 m^3, of which about 10% is furniture. Two adults live in an apartment. There are four plants in the bedroom. The CO_2 concentration is evaluated during the night under different modes of natural ventilation by the window in combination with open interior doors to other rooms. It was always ventilated for 10 minutes before measuring. The initial carbon concentration dropped to 800 ppm. Then two people stayed in the bedroom for 8 hours. For measurement, the Testo 480 climate measuring instrument was used with accessories for measuring CO_2, temperature and humidity. The precision of the measuring instruments Testo 480 and probe air quality and are presented in Table 1.

Table 1. Description of measuring instrument Testo 480 and probe air quality

Parameter	Measuring range	Resolution	Accuracy
Temperature	0 to +50 °C	0.1 °C	±0.5 °C
Relative humidity	0 to +100 % RH	0.1 % RH	± (1.8% RH + 0.7% of mv)
CO_2 concentration	0 to +10000 ppm	1 ppm	± (75 ppm + 3 % of mv)

3. Results and discussions

The first measurements were carried out with the closed windows and the closed door to the room. The second-day window was closed and the door to the hall opened. The third day of the measurement took place with the window in the micro-ventilation mode and the door to the room was closed. On day four, the tilting mode was set at the window and the door was closed. On the fifth day, the window was open and the room doors were closed again.

Table 2. The measured CO_2 concentration

Day	CO_2 concentration at the start of measurement [ppm]	Minimum CO_2 concentration during measurement [ppm]	Maximum CO_2 concentration during measurement [ppm]	Difference between final measured value and initial value [ppm]
1	800	800	2399	+1599
2	800	800	2112	+1312
3	800	800	2198	+1398
4	800	800	887	+87
5	800	423	800	-377

Residential rooms must be provided with sufficient natural or forced ventilation and must be sufficiently heated with the possibility of regulating the internal temperature. For ventilation of the living rooms, a minimum amount of fresh air of 25 m^3 per hour per person or a minimum ventilation intensity of 0.5 per hour must be provided during the stay of the persons. Carbon concentration is an indicator of air quality and its "exhalation". The adult CO_2 concentration (Table 2) of the expired air is approximately 40000 ppm. Residential rooms must be ventilated in such a way that the maximum permissible concentration of carbon dioxide of 1000 - 1500 ppm is maintained during the stay of persons. According to Pettenkofer, the concentration of carbon dioxide should be below 0.1% (1000 ppm = 1938 mg/m^3) for the comfort and well-being of the occupants. Table 3 shows the effects of carbon on the human body at various concentrations.

Table 3. Effects of CO_2 on the human body

CO2 concentration [ppm]	Effects
Approx. 350 - 400	Level of the outdoor environment
< 1000	Recommended indoor CO_2 level
1200 - 1500	Recommended maximum indoor CO2 level
1000 – 2000	Symptoms of fatigue and reducing the concentration
2000 - 5000	Headaches
5000	Maximum safe concentration without health risks
> 5000	Nausea and increased heart rate
> 15000	Breathing problems
> 40000	Possible loss of consciousness

In outdoor environments, the CO_2 concentration is around 350-400 ppm depending on location. Of course, in nature, the concentration will be different than in the center of a big city. The exterior CO_2 concentration was measured at 387 ppm during the first night of measurement. Table 4 indicates CO_2 concentration in the interior above the outdoor concentration (difference) according to ČSN 15251 Indoor environmental input parameters for design and assessment of energy performance of buildings- addressing indoor air quality, thermal environment, lighting and acoustics.

Table 4. The CO_2 concentration in the interior above the outdoor concentration according to ČSN 15251

Category	CO_2 [ppm]
I	350
II	500
III	800
IV	>800

Category I high level of expectation is used for environments with special requirements, for people with disabilities, etc. Category II Normal Environment is used for new and refurbished buildings. Category III acceptable environment is used for old buildings.

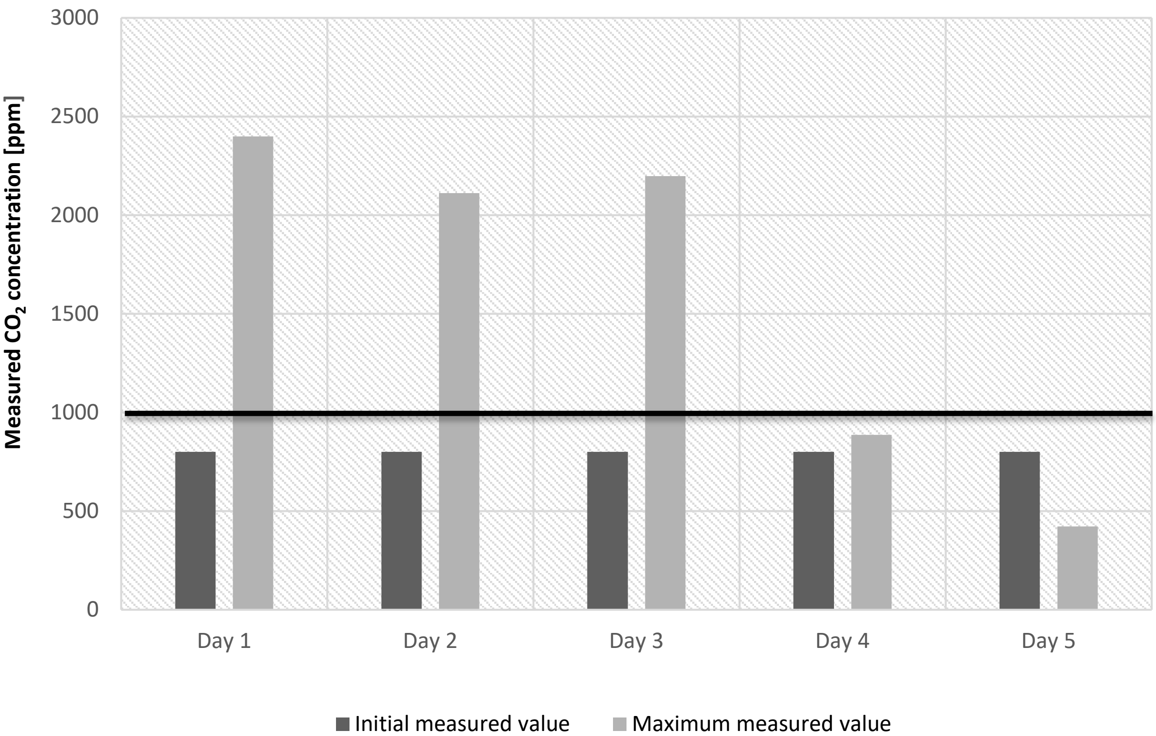

Figure 1. The measured concentration of CO_2 and their assessment

Figure 1 shows the initial and maximum measured values of carbon dioxide concentration for each ventilation modes. Concentrations during the night are evaluated under different natural ventilation modes in combination with open interior doors to other rooms. The first measurements were carried out with the closed windows and the closed door to the room. The maximum measured CO_2 concentration was 2399 ppm. This variant is evaluated as the worst and the initial value of 800 ppm increased by 1599 ppm during the night. With a carbon concentration of more than 2000 ppm, headaches can occur and the body does not regenerate during the night and does not rest as in fresh air with higher oxygen content. The next day the window was closed and the door to the hall was opened. In this case, the maximum measured carbon concentration was 2112 ppm. Even this value exceeds the maximum recommended indoor CO_2 level. On the third day, the window was set to micro-ventilation with the room door closed. The maximum CO_2 concentration, in this case, was 2198 ppm and thus again unsatisfactory. On the fourth day, the window was set to ventilation mode (tilting position) and the door was closed. The maximum carbon dioxide concentration during the night was 887 ppm. In this case, the requirement for the recommended level of indoor carbon dioxide concentration was met. On the fifth day, the window was opened and the room door was closed. This variant came out best because the initial value of 800 ppm was even 377 ppm reduced during the night, thus almost equalizing the outdoor CO_2 concentration and the requirement for the recommended indoor CO_2 level was fulfilled.

4. Conclusions

Carbon dioxide is a natural gas component of the atmospheric air. This gas is odorless. People do not have natural receptors to detect it. However, at a higher CO_2 concentration, people react with the loss of concentration, increased malaise, and can lead to the fatigue associated with e.g. headaches and nausea. In the natural environment, the carbon concentration is around 350-400 ppm, in the industrial areas, the value is slightly higher. Approximately 20% of the population begins to react negatively at the CO_2 concentration of about 1000 ppm. For the control systems, this value is often set as a limit for controlling the air conditioning unit performance or an air exchange in the room.

The results show a significant effect of ventilation on the air quality. The results show that only natural ventilation through the new tight windows in renovated apartment buildings is insufficient. In this case, it is appropriate to consider the installation of the air-conditioning units. In the winter months, it is almost impossible to provide fresh air in the interior while ensuring an acceptable room temperature. By regulating the ventilation according to the CO_2 concentration, the requirement for the supply of “fresh” air for the human is taken into account and, as a result, the other undesirable components are ventilated from the interior.

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