

# Indoor Environment in Residential Prefabricated Buildings

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**Abstract.** The contribution presents results of the experimental measurement of indoor air quality in residential prefabricated buildings. People spend about 90% of their life in the indoor environment of buildings. Hygrothermal parameters and indoor air quality are the essential component that define the quality of the indoor environment. The results of case study characterize the quality of the indoor environment of the ordinary occupants in housing unit of residential prefabricated building. A current problem of revitalized prefabricated buildings is inadequate air exchange and related thereto to poor indoor air quality. The experimental measurements were carried out just before and at the beginning of the heating season (from 1<sup>st</sup> October to 30<sup>th</sup> November 2016). Heating season was launched in the middle of experimental measurement. The wireless indoor sensor Elgato Eve Room was used for measurements. The obtained values of indoor air temperature [°C], relative humidity [%] and indoor air quality [ppm] are describe and analysis in this study. The results of the study indicate that the values of temperature and indoor air quality meet optimal levels during the experiment with nuances. The mean air temperature in the indoor environment is 22.43 °C. The temperature of the indoor environment is held at the optimum level (18-24 °C) for 94.50% time of the experimental measurements. In addition, the indoor air quality in the context of the content of harmful volatile organic compounds (VOCs) has been excellent for almost 91% time of the total experiment. However, the values of relative humidity were less than the optimum value nearly 40% of the total observed time. The mean 10-minutes values of relative humidity during the heating season is about 10% lower than the mean 10-minutes relative humidity before the heating season.

## 1. Introduction

Indoor environment has a significant impact on the health, comfort and performance of occupants. According to the principles of sustainability of buildings, it is necessary to ensure a quality indoor environment with respect to thermal and humidity comfort, lighting, acoustic, ventilation, hygiene and aesthetics [1, 2]. The indoor environment is defined by a number of partial elements - thermal and humidity parameters, ventilation, lighting, acoustics, odours, and microbial, aerosol and ionization factors. The most elements of internal environment are affected by the method and the intensity of ventilation. In the context of achieving energy savings, the current constructions are characterized by high level of the building airtightness. The lower the air leakage of the building is, the higher the airtightness is. Airtightness is the ability of the construction to not to lay off air [3]. Inadequate supply of fresh air negatively affects the quality of the indoor environment and increases the risk of incidence of Sick Building Syndrome (SBS) [4]. Currently almost 85% of occupants suffer from the SBS disease. Symptoms of the Sick Building Syndrome involve deterioration of asthma and allergies,



burning, itching and watery eyes, stuffy nose or chronic rhinitis, drought and scratching in the respiratory tract, headache, fatigue during the day, depression, neurosis, insomnia or sleep disturbances and impaired concentration [5].

## **2. Thermal-humidity microclimate and indoor air quality**

Thermal-humidity microclimate is part of the environment formed by heat flows and humidity flows. This element the microclimate is one of the most significant elements to ensure health and well-being of indoor environment. Among others, the hygrothermal microclimate plays an important role in terms of durability of building materials, building and manufacturing technology. The indoor air temperature and relative humidity of indoor air are closely interdependent and conditional [6].

Thermal comfort is a state of balance between the person and indoor environment without the overburdening thermoregulatory system. Thermal comfort can be also defined as the metabolic balance between heat flow and flow of the exhaust heat from the body at optimal levels of physiological parameters without changing the heating or cooling of the human body. Both the heat flows can be controlled in different ways for example by altering the activity or various clothes. Thermal comfort is a subjective feeling. Thermal sensation in overall body is affected by local body parts [1]. The optimum indoor air temperature is considered to range from 18 to 24 °C in the heating season [6]. Summer temperatures may be a slightly higher. The difference between the temperature of the surrounding surfaces (walls) and the indoor air temperature should not be higher than 2 °C at airflow velocity of about 0.2 m/s. This optimum range of indoor air temperature is characteristic for maximum performance of building occupants. The higher indoor temperature is, the lower the performance of occupants is. Performance decreases approximately 25% when the indoor air temperature is 27 °C. Only half of performance is assumed at an indoor air temperature of 30 °C. The probability of mortality due to respiratory diseases, high blood pressure, and stroke risks is higher when indoor air temperature is lower than 20 °C [7].

The humidity in residential indoor environment should be about 40%, in the range 30% to 50%. Relative humidity should not exceed 65% during the summer. Excessive humidity can lead to degradation of materials and the growth of moulds. Conversely, too low humidity damages mucous membranes (drying) and decreases body immunity. In the cold season, humidity should be at least 30%.

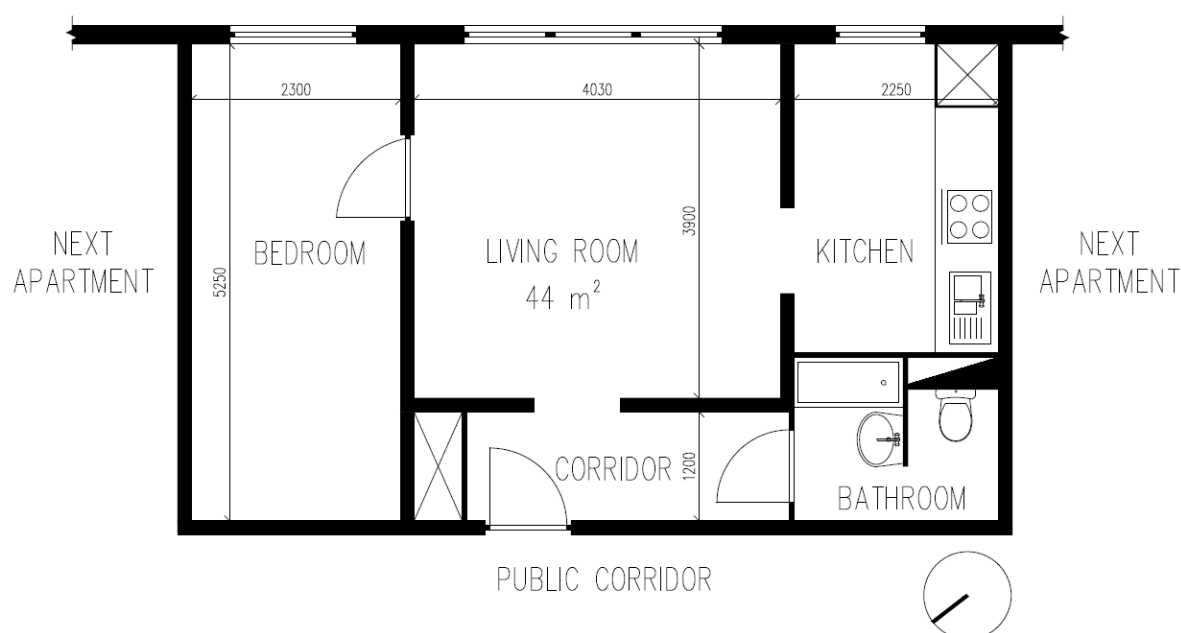
Indoor air quality is defined by a measure of ventilation and concentration of pollutants, such as radon, carbon dioxide and carbon monoxide, volatile organic compounds (VOCs), molds and other allergens, ozone, particulates and next [5]. The concentration of carbon dioxide has been regarded as a major indicator of the indoor air quality for a long time. There are many of studies dealing with the quality of the indoor environment only in terms of the concentration of carbon dioxide (CO<sub>2</sub>) [8, 9]. Maximum acceptable limit for concentration of carbon dioxide in indoor environment is 1500 ppm. [5]. Today, attention is also devoted to concentrations of volatile organic compounds as the natural human and animal odours, perfumes, fumes from furniture, carpets, paints, coatings, adhesives, bins, cleaning and detergents. Volatile organic compounds include a variety of chemical groups, such as aromatic hydrocarbons, ketones, alcohols, alkanes, aldehydes and next. Benzene, toluene, ethylbenzene and xylene (so called BTEX) are among the VOCs with a significant impact on human health [10].

## **3. Experimental measurements**

Prefabricated panel buildings account about a third of the housing stock in the Czech Republic. There are approximately 200 000 of prefabricated panel buildings with over 1.2 million apartments. A large share of prefabricated panel buildings has been revitalized (insulation of the building envelope, replacement of windows). Great problems of these buildings are sealing the ventilation slots and replacing the original windows with new and very tight windows. There is risk of a rise of harmful substances and the deterioration of the quality of the indoor environment due to inadequate ventilation.

The measurements were carried out in the apartments in the residential prefabricated panel building located in the centre of Ostrava, Czechia. The building is revitalized – thermal insulation and new windows. Heavy industry and power industry are a significant source of air pollution in Ostrava. Adverse dispersion conditions with the presence of smog are typical for the respective location. The most common pollutants are particulate matter (dust) and carbon monoxide (CO), nitrogen oxides (NO<sub>x</sub>), sulphur dioxide (SO<sub>2</sub>), ammonia and volatile organic compounds.

The selected apartment is located on the second floor of the prefabricated panel building. The scheme of floor plan of the apartment is shown in figure 1. This is a two-room apartment with a kitchen. Total floor area of apartment is approximately 44 m<sup>2</sup>. Headroom of the apartment is 2.6 m. The expected volume of air is 114.40 cubic meters. All windows of the apartment are oriented to the southeast. The apartment is ventilated entirely by windows. Two persons normally occupy the apartment. The apartment was standard used throughout the measurement.



**Figure 1.** Scheme of floor plan of the apartment

The thermal-humidity parameters and indoor air quality are investigated in this study. Experimental measurements were carried out from 1 October to 30 November last year (just before and at the beginning of the heating season). The indoor air temperature [°C], relative humidity [%] and indoor air quality [ppm] were continuously measured in 10-minutes cycles in selected in residential prefabricated panel building. The mean daily outdoor temperature for Ostrava (Mošnov) is 8.3 °C in October and 5.0 °C in November.

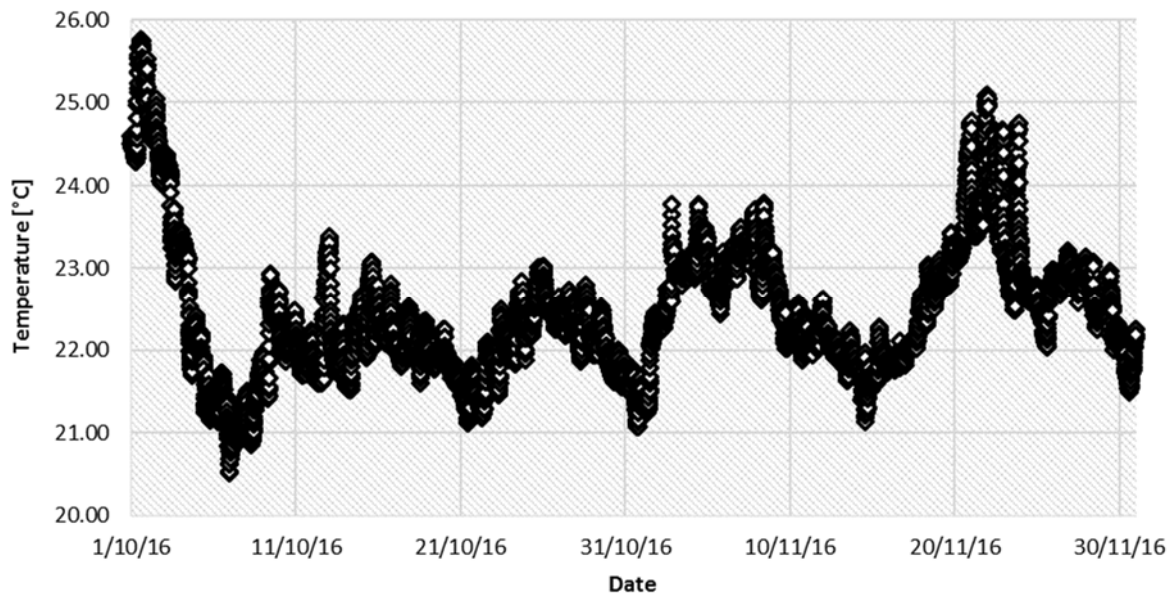
The wireless indoor sensor Elgato Eve Room is used for experimental measurements. MEMS (Micro Electro Mechanical System) MOS gas sensor component is used for VOC detection. The integrated high-performance sensor (AS-MLV-P2) into Elgato Eve Room detects chemical selected groups of VOCs - alcohols, aldehydes, ketones, organic acids, and amines, aliphatic and aromatic hydrocarbons. The measured VOC level is represented by level of CO<sub>2</sub> equivalent [ppm]. The photoionization detector (PID) with UV lamp ppBRAE 3000 (range of 1 ppb to 10000 ppm and measurement accuracy ±3%) and Ultra-fast electronic nose zNose (measurement accuracy ±2%) are used for measuring and analysis of volatile organic compounds.

#### 4. Results and discussions

The results include data of altogether 61 days (1 464 hours) covering from 1<sup>st</sup> October to 30<sup>th</sup> November for the analysis. In total 8 757 measurement points are recorded in 10-minutes cycles. The results are presented graphically for a better comprehensibility.

##### 4.1. Indoor air temperature

The obtained values of indoor air temperature are shown in figure 2. The minimum measured indoor air temperature is 20.52°C. Indoor air temperature in the apartment has never been less than optimal temperature (18 °C) during the experiment. The mean 10-minutes indoor air temperature is 22.43 °C. Maximum value of indoor air temperature is 25.76 °C. Indoor air temperature exceeded the upper limit of the optimum temperature for a total of 80.52 (5.50%) hours. Graphical representation of obtained values shows significant fluctuations from the mean. The beginning of the heating season (1<sup>st</sup> November) is evident from the graph.



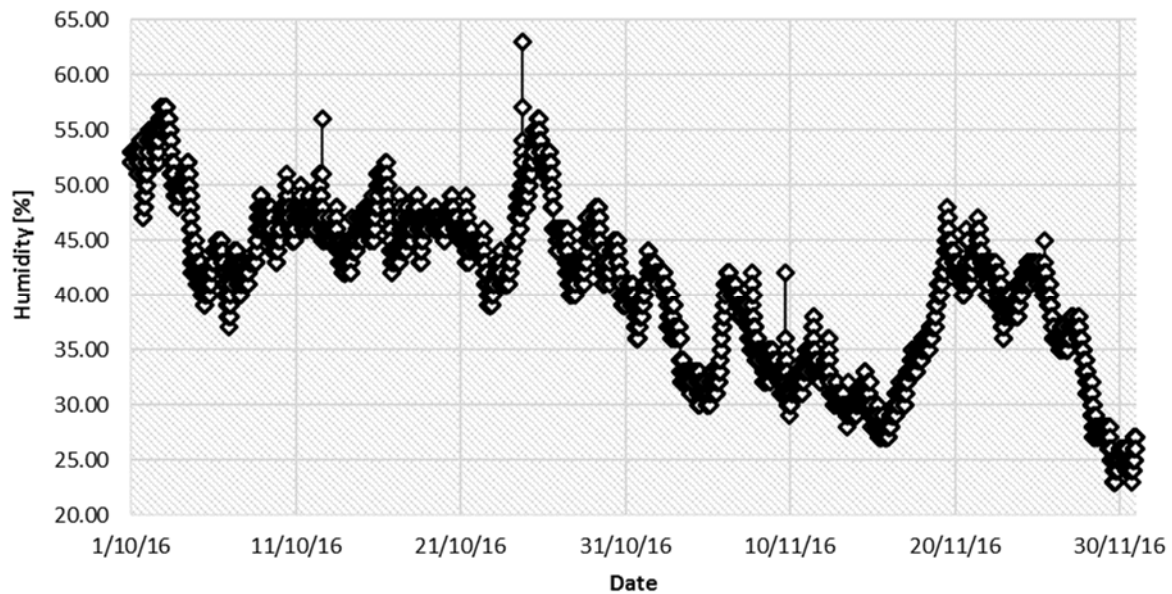
**Figure 2.** Results of measured temperatures in 10-minutes cycles

**Table 1.** Evaluation of indoor temperature

Temperature [°C]	Frequency [-]	Relative Frequency [%]
< 18	0	0%
18 – 24	8275	94.50%
> 24	482	5.50%

##### 4.2. Relative humidity

The result of the relative humidity is shown in figure 3 and table 2. The mean relative humidity in 10-minutes cycles is 40.56%. According to the diagram, a sharp drop in relative humidity characterizes the beginning of the heating season. The mean relative humidity before the beginning of the heating season is 45.88%. The optimum level of relative humidity values is detected for approximately half time of the experiment.



**Figure 3.** Results of measured relative humidity in 10-minutes cycles

**Table 2.** Evaluation of the indoor relative humidity

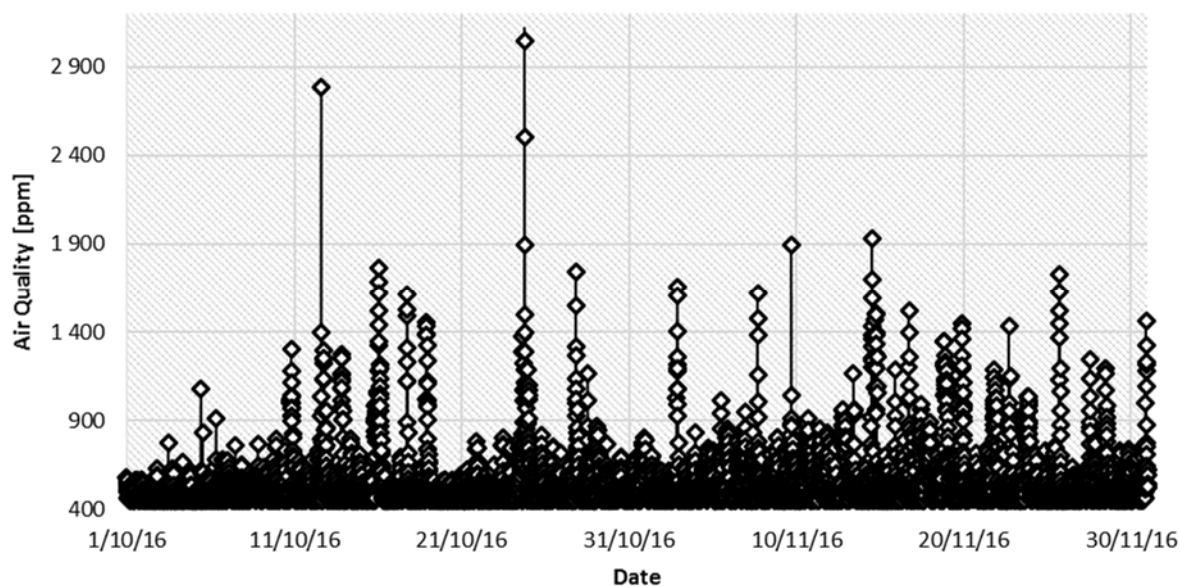
Indoor relative humidity [%]	Frequency [-]	Relative Frequency [%]
< 40	3277	37.42%
40 – 50	4719	53.89%
> 50	761	8.69%

#### 4.3. Indoor air quality

According to figure 4 and table 3, the indoor air quality is excellent for almost 91% time of the monitored period. Inferior air quality is recorded for 2.34 hours during total measurement period (0.16%). Indoor air is contaminated during this period and it is recommended air exchange. Poor indoor air quality is typical for 0.44 hours. Based on the measurement results it can be stated that the quality of indoor air is most of the period is acceptable. Based on interviews with users of the apartment, it can be deduced that poor air quality is typical for the cooking and cleaning (vacuuming).

**Table 3.** Evaluation of the indoor air quality.

Air Quality	CO <sub>2</sub> equivalent [ppm]	Frequency [-]	Relative Frequency [%]
<b>Excellent</b>	< 700	7 951	90.80%
<b>Good</b>	700 – 1100	658	7.51%
<b>Fair</b>	1100 – 1600	131	1.50%
<b>Inferior</b>	1600 – 2100	14	0.16%
<b>Poor</b>	> 2100	3	0.03%



**Figure 4.** Results of measured air quality in 10-minutes cycles

## 5. Conclusions

The residential prefabricated panel buildings and their revitalization in order to improve energy performance of brings many problems. The majority of these buildings are ventilated by windows. Replacement of windows and sealing the ventilation slots brings a wide range of risks to the health and comfort of building occupants. The concentration of pollutants in indoor environments rises in case of insufficient ventilation. The uncontrolled increase relative humidity is another of the problems of insufficient ventilation in buildings. High values of relative humidity in the interior reduces the comfort of users, but also threatens the structure and reduces their life. In accordance with the principles of sustainable development, it is necessary to reach a compromise between energy savings and indoor air quality (comfort and health of occupants) not only in the construction of new buildings, but also in the reconstruction and revitalization of existing buildings. The results of the study show that attention should be paid to relative humidity.

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