Indoor Air Pollution in Housing Units

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Abstract. Pollution and poor quality of the indoor environment is a common problem in today's residential buildings. These problems are reflected in the well-being and health of the users of these buildings. Targeted identification of the various harmful substances (pollutants) is essential for understanding the interactions of components of the internal environment for the welfare and health of building users. The Czech housing units were selected for screening investigation of indoor air quality. Measuring of indoor chemical factors was performed during the year 2019. The indoor levels of TVOC, nitrogen oxides, indoor radon, and particulate matters PM₁₀ were measured. The results provide introduce data on indoor air quality concerning seasonal changes which were in correlation to air change rate. These results, introduced in this paper, help to understand the indoor pollutants occurrence and help to design next more focused studies.

1. Introduction

The issue of quality indoor air in connection with the well-being and healthy users of buildings is currently very topical. Building interiors are considered a significant source of harmful substances. These substances are referred to as indoor air pollutants. With the requirement to ensure a healthy and comfortable indoor environment, the efforts of the scientific and lay public to understand the mutual multidisciplinary relationships of the creation of the indoor environment are also growing. Most people spend up to 90% of their time indoors, especially at these COVID times [1]. The quality of the environment reflects the location of construction, or the region, different climatic conditions, lifestyle, and local building habits. Highly developed countries with modern HVAC technologies available for the operation will face a growing problem with the quality of the indoor environment. Sources of indoor air pollution include the burning of fossil fuels for heating and cooking, smoking, emissions from building materials, furniture, carpets, the use of cleaning chemicals, improper ventilation or improper air conditioning maintenance, and infiltration of atmospheric pollutants from the surrounding outdoor environment [2-4].

The buildings have been designed to protect users from adverse weather conditions and provide them with the necessary privacy and intimacy. In the context of sustainable construction, increasing attention is being paid to the energy efficiency of buildings. The aim is to minimize energy consumption in the operation of the building and maximize the use of renewable energy sources. The current construction of the buildings focused on minimizing the heated volume and increasing the airtightness of the building envelope. Buildings are no longer naturally ventilate through building
envelope leaks. Insufficient natural diffusion of air in combination with a reduced ventilation regime leads to an increase in the concentration of pollutants in the indoor air, which can cause a number of health problems. The interior of buildings can be a source of pollutants. Other pollutants helped get into the interior from outside air or the ground (e.g., Radon). The qualitative and quantitative parameters of the indoor environment must be assessed during the design of the building [5].

The indoor environment exposes the human subject through physical, chemical, and biological components. The chemical pollutants have the dominant position of the indoor environment influence. From the point of view of the effects on the health of building users, the chemical components of the indoor environment are preferred, especially substances of a toxic nature. The occurrence of a pollutant and its concentration in the indoor environment is defined by the balance equation between the emissivity into the indoor air and the intensity of ventilation, i.e., the supply of fresh air and the discharge of polluted air by the pollutant.

Insufficient and poor indoor air quality is considered to be a significant cause of the development of the Sick Buildings Syndrome (SBS). However, it is necessary to realize that the internal environment is extremely multidisciplinary, and a number of other aspects contribute to the development of SBS. Chemical pollutants, such as volatile organic compounds, nitrogen oxides, radon, particulate matter, and many others can produce Sick Building Syndrome symptoms in the indoor environment of the buildings. The specific determination of the cause of the development of the Sick Building Syndrome is still unclear. It can be assumed that there are connections between psychological factors, the intensity of ventilation, and the level of hygiene in the indoor environment of buildings [6, 7].

The housing units as residential prefabricated panel buildings in order to improve the energy performance of bringing many problems. The majority of these buildings are ventilated by windows. Replacement of windows and sealing the ventilation slots bring 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. 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 [8, 9].

2. **Chemical pollutants screening measurements**

Volatile organic compounds expressed as TVOC, nitrogen oxides, radon, and PM10 concentration were measured in the indoor environment at a screening study across the South Czech as part of the Czech Republic. These chemical pollutants occurrence associated with indoor air quality were collected to provide entrance screening data on indoor air quality in housing units. The study was performed in multi-story housing units which were casually selected and accessed by owners of apartments. The buildings are built of concrete or reinforced concrete. The floor area of the monitored housing units ranges from 45 to 85 square meters. All of the monitored housing units are naturally ventilated using windows. Heating in all surveyed housing units has been assured by the central heating system. Gas is used to prepare meals. The intensity of ventilation during the year reflects the local climatic conditions typical of the temperate climate of Central Europe. More than 100 screening measurements were performed between October 2018 and November 2019. The measuring instrument was installed in the centre of the room at the height of 1 050 mm from the floor. This is the height characteristic of the breathing zone of a seated person. Table 1 characterizes pollutants, their sources, and possible negative health impacts and problems.
A number of building and household materials may be sources of volatile organic compounds (VOCs). Users will be surrounded in the living space by a large number of internal devices and building materials releasing harmful substances. Already performed measurements have found that in the interior the air is even 2 - 5 times more polluted than in the outdoor environment. Generally, the air outside naturally dilutes VOCs. Indoors, sources of VOCs are divided into short-term and long-term emission sources. In high concentrations, it usually has a short-term effect, for example, when applying paints or when cleaning households with the use of a large number of disinfectants and cleaning agents. In the long run, VOCs are released, for example, from building materials, wallpaper, carpets, or furniture. Cigarette smoke producing hydrocarbons, formaldehyde and other harmful substances is also an important source of pollutants. The effects of volatile organic compounds on human health can vary widely. The effects of volatile organic compounds depend on a number of factors such as the duration of exposure, the type of volatile organic compound or the concentration. It is generally recommended to use materials and elements that are low-emission. The buildings are mostly classified as non low-polluted. The building can be defined as low polluted, if the majority of materials are low polluting. Traditional natural materials are generally used among low-end sources. They are known to be safe in terms of TVOC emissions production and to meet the required value for low-emission materials, i.e., 0.200 mg/(m².h) [10]. In screening monitoring, TVOC concentrations were monitored using by photoionization detector with UV lamp—ppb RAE 3000 (RAE Systems, Inc., San Jose, CA, USA). High concentrations of volatile organic compounds usually indicate insufficient ventilation or poor ventilation (very similar to the concentration of Carbon dioxide) [11].

Nitrogen oxides as a chemical pollutant with increased frequency of exposure and possible health effects were also classified as an indoor pollutant with high priority. Nitrogen dioxide and nitric oxide may be present in concentrations in the indoor environment with a demonstrable effect on health. The basic source of nitrogen oxides are emissions from road transport and from stationary sources burning fossil fuels. The source in the indoor environment is the use of gas for cooking, heating, and hot water. From the point of view of the impact on human health, nitrogen dioxide is considered to be extremely toxic. Within the screening measurements for monitoring the nitrogen oxides was used passive samplers Model 410 Nitric Oxide Monitor and Model 401 NO₂ Converter. The measurement concentration range is 0 - 2000 ppb with a precision of ±1.5 ppb. The intensity of gas combustion varied in the range 0.2 – 1.0 m³.h⁻¹ [12].

Radon is part of the theme of every indoor air of buildings. In the prescribed geographical areas defined by the pedosphere, the rate of radon release is higher than elsewhere. Depending on the building design and particularly on how they are vented and heated, radon and its decay products may be trapped within buildings and accumulate in them. An important source of radon in the living spaces of buildings is especially the subsoil. The source of radon in soil air is natural radionuclides present in the earth's crust, in which radioactive transformation produces radioactive gases from two basic decay series of uranium (²³⁸U) and thorium (²³²Th). The main transport mechanism is the convection of soil air through cracks and leaks in transitions in the foundation slabs and basement walls. An important factor that affects this transport is especially the size of the vacuum in the building. The tightness and integrity of foundation and basement structures play a decisive role in the indoor radon concentrations. The resulting concentration depends on the total area of substructures and their leaks, the

Table 1. Measured indoor pollutants, assumed sources, and prospective health effects.

| Pollutant | Source          | Health effects          |
|-----------|-----------------|-------------------------|
| TVOC      | Materials       | SBS, acute, chronic risk|
| NOx       | Combustion      | SBS, acute risk         |
| Radon     | Soil, materials | Chronic risk            |
| PM₁₀      | Materials       | Chronic risk            |

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concentration of soil radon in the subsoil, the permeability of the subsoil and the intensity of air exchange. Another important source of radon can be raw materials and building materials intended for construction containing a higher concentration of radon. Radon is scattered throughout the room due to the air flow. However, its concentration in a given room varies considerably with time. This is caused by changes in the multiplicity of air exchange and in the speed of radon supply to the building caused by changing variables such as heat and pressure difference, infiltration, wind force, ground permeability and others. These changes can be short-term, but also long-term, during the seasons and years [13, 14]. Due to the elimination of the influence of climatic factors, the measurements were always performed in individual periods of the year under approximately the same meteorological conditions. Radon Progeny Monitor - the RPM-256 system was used to monitor the concentration of Radon in the interior of buildings. The mean radon concentrations as well as the mean standard deviation were determined from the collected data.

In addition to the gaseous fraction, dust particles of various nature and size occur in the indoor air. Particles harmful to humans have an aerodynamic particle diameter of less than or equal to 10 μm and are referred to as PM<sub>10</sub> particles. Dust particles can be emitted from a natural source, e.g., during volcanic activity, or from an anthropogenic source (caused by man), e.g. during fossil fuel combustion, transport, etc. Dust pollution is currently one of the main air quality problems in the Czech Republic. The amount of suspended particles in the air depends on the season. PM<sub>10</sub> concentrations increase during the colder period of the year, mainly depending on the seasonal use of heat sources and also due to worsened dispersion conditions, which are usually more common in the winter months. Dust in building interiors is a complex of particles of various sizes. Due to gravitational forces, larger particles settle faster on the surrounding surfaces, smaller particles stay in the indoor air for a longer time [15]. Based on the previous study [16], it is clear that an increase of relative humidity by 10% will cause a decrease in PM<sub>10</sub> concentration by 10 μg·m<sup>-3</sup>. The concentration of PM<sub>10</sub> is determined by a weighing method by filtering the air through a filter. Gravimetric measurement is used to determine the amount of trapped dust particles. The Synpor nitrocellulose filter with pore size 0.8 μm and with diameter of 35 mm is used for sample collection. The VPS 2000 device (Envitech) with constant air flow is used for sample analysis.

### 3. Volatile organic compounds screening results

Most reported TVOC concentrations in studied housing units’ environments were below 100 μg·m<sup>-3</sup> and few exceed 300 μg·m<sup>-3</sup>. The results of monitoring showed that in a total of 39% of the monitored indoor environment of households exceeded the recommended value of TVOC (200 μg·m<sup>-3</sup>) for the indoor environment (Table 2). It is clear that the indoor environment of residential buildings is a significant source of emissions of volatile organic compounds. These concentrations are higher than in the external environment. With short-term exposure of measured concentrations, only sensory (sensory) effects on users of objects can be expected. Irritation and dryness in eyes, nose, air ways and skin are among the typical sensory symptoms. In terms of long-term exposure, a negative health impact on the organism cannot be ruled out. Other effects such as headache, concentration disorders, motor disorders, dizziness, nausea and vomiting are observed when exposed indoors with concentrations higher than 200 μg·m<sup>-3</sup>.

**Table 2.** Seasonal changes of indoor TVOC values in housing units.

| Season  | Mean TVOC concentration [μg·m<sup>-3</sup>] | Mean standard deviation [μg·m<sup>-3</sup>] | Mean air change [h<sup>-1</sup>] |
|---------|---------------------------------------------|---------------------------------------------|----------------------------------|
| Winter  | 127.1                                       | 8.6                                         | 0.3 – 0.5                        |
| Spring  | 89.8                                        | 7.9                                         | 0.5 – 0.7                        |
| Summer  | 55.8                                        | 8.3                                         | 0.9 – 1.1                        |
| Autumn  | 70.4                                        | 8.2                                         | 0.7 – 0.9                        |
4. Indoor NO\textsubscript{x} screening results

However, in terms of indoor air quality, sources of nitrogen oxides located directly in buildings are more important. The results of monitoring the concentrations of nitrogen oxides in housing units spaces not only confirmed their excessive occurrence in the indoor environment of buildings but the dynamics of increasing and decreasing concentrations during the combustion process for various tight window constructions were monitored (Table 3). Average annual NO\textsubscript{x} concentrations in ambient air from 20 to 90 μg.m\textsuperscript{-3} were measured. Maximum hourly concentrations varied from 75 to 1015 μg.m\textsuperscript{-3}. High concentrations, which pose a serious health risk, are achieved even with short-term exposure to the effects of combustion. The influence of cooking on the concentration of nitrogen oxides was realized in order to determine the degree of influence. In the indoor environment of buildings, during gas combustion, values of more than 200 μg.m\textsuperscript{-3} were reached for several days, with maximum hourly NO\textsubscript{x} concentrations of around 2000 μg.m\textsuperscript{-3}. Mean values of NO\textsubscript{x} concentrations were relatively high and show significant seasonal changes. These changes are caused by changes in emission and dispersion conditions. When evaluating the occurrence of NO\textsubscript{x} in the indoor environment of buildings, we perceive the load of outdoor air as background values. Mean indoor NO\textsubscript{x} concentrations are evident within Table 3.

| Season | Mean NO\textsubscript{x} concentration [μg.m\textsuperscript{-3}] | Mean standard deviation [μg.m\textsuperscript{-3}] | Mean air change [h\textsuperscript{-1}] |
|--------|-------------------------------------------------------------|-------------------------------------------------|--------------------------------------|
| Winter | 182.8                                                       | 6.4                                            | 0.3 – 0.5                            |
| Spring | 159.1                                                       | 5.9                                            | 0.5 – 0.7                            |
| Summer | 60.4                                                        | 5.0                                            | 0.9 – 1.1                            |
| Autumn | 79.3                                                        | 4.8                                            | 0.7 – 0.9                            |

5. Indoor radon screening results

Although there are a number of studies on the effect of radon on the well-being and health of building users, there is still no clear consensus as to what level of radon concentration already poses a health risk. It is necessary to say that standard limiting value need not be conceived as a limit value, but upper value for alternatives, which should lead in practice to as low level as reasonably possible (Table 4). The indoor radon value of 100 Bq.m\textsuperscript{-3} was exceeded in 57% of indoor spaces. The maximum level of 687 Bq.m\textsuperscript{-3} and the average radon activity of 93 Bq.m\textsuperscript{-3} were measured. On the other side, the level of 200 Bq.m\textsuperscript{-3} was exceeded only by 10%. The outdoor radon concentration between 8 – 15 Bq.m\textsuperscript{-3} was measured.

| Season | Mean Radon concentration [Bq.m\textsuperscript{-3}] | Mean standard deviation [Bq.m\textsuperscript{-3}] | Mean air change [h\textsuperscript{-1}] |
|--------|-------------------------------------------------|-------------------------------------------------|--------------------------------------|
| Winter | 163.9                                           | 6.2                                            | 0.3 – 0.5                            |
| Spring | 156.4                                           | 6.5                                            | 0.5 – 0.7                            |
| Summer | 61.2                                            | 4.9                                            | 0.9 – 1.1                            |
| Autumn | 55.7                                            | 4.3                                            | 0.7 – 0.9                            |

6. Indoor particular matter screening results

This screening study described PM\textsubscript{10} occurrence related to seasonal changes in housing units. According to the performed experimental measurements, the relative humidity of the air and the intensity of the air exchange have a major impact on the concentrations of dust particles. The high concentrations of dust particles reflect the problematic internal environment of the building, which needs to be given increased attention in the area of monitoring and, if necessary, the adoption of measures. The maximum mean concentration of PM\textsubscript{10} (108.3 μg.m\textsuperscript{-3}) was noted for the winter season.
because of low values of relative humidity 25 - 35\% (Table 5, Figure 1). The mean value of PM\(_{10}\) concentration during the spring period was 97.7 \(\mu g.m^{-3}\). The lowest mean value of PM\(_{10}\) concentration (49.6 \(\mu g.m^{-3}\)) was measured during the summer season by value of relative humidity 60 - 65\%.

| Season | Mean PM\(_{10}\) concentration \([\mu g.m^{-3}]\) | Mean standard deviation \([\mu g.m^{-3}]\) | Mean air change \([h^{-1}]\) |
|--------|---------------------------------------------|---------------------------------------------|-----------------------------|
| Winter | 108.3                                       | 5.2                                         | 0.3 – 0.5                   |
| Spring | 97.7                                        | 5.9                                         | 0.5 – 0.7                   |
| Summer | 49.6                                        | 4.1                                         | 0.9 – 1.1                   |
| Autumn | 65.7                                        | 4.7                                         | 0.7 – 0.9                   |

Figure 1. The concentration of monitored pollutants depending on the period of the year.

7. Conclusions
The contribution confirmed that in the indoor environment of buildings, the occurrence of harmful substances (volatile or semi-volatile organic compounds, nitrogen oxides, radon, solid inorganic particles, etc.) is pretty high and must be excluded or limited to an acceptable level. The current problem is the overall sealing of buildings to save energy. The increase in harmful substances in the interior is a negative impact, as the natural flow of air is prevented. Insufficient ventilation or a strong source of pollutant emissions reflects the presence of high concentrations of chemical pollutants in buildings. The source control measures in the first case should be taken. In the second case, it is necessary to ensure a sufficient intensity of ventilation, i.e., the removal of polluted air and the supply of fresh air. Sufficient air change should be provided, especially aimed at controlled ventilation regarding indoor air pollution from buildings themselves. Buildings should be designed and constructed in such a way that they do not have a negative effect on the environment with which they interact during their operation. The quality of the indoor environment in housing units was also negatively affected by other boundary conditions, which independently enter into the interaction of the building and the environment. Conscious human activity also plays an important role in its creation.
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