The importance of indoor air quality (IAC) monitoring

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Abstract. Air pollution is already a global public health crisis, as it kills seven million people each year, according to the World Health Organization. Presently, a correlation between health and air pollution levels recorded in the past exists. The paper presents series of instruments concerning IAC (Indoor Air Quality) measurements and focuses on indoor air quality measurements taken in different closed spaces, as example. Based on the concentration values detected, the conclusion of the paper indicates that, depending on the technological process or activity in enclosed spaces, it is mandatory to check the IAQ. This action must be taken as prevention, in order to reduce potential health risks upon humans, acting in their homes, or schools and offices or industrial halls, in general in closed spaces, even when artificially ventilated.

1. Preamble

Air quality in general is a dominant exposure to risk for humans, even if it results during outdoor or indoor exposure. Still, 50-90\% of the body’s intake during a lifetime is air inhaled in the home and closed/limited spaces. Long-term exposure to air pollutants has a detrimental effect, but also it is detectable in time. More recently, data reported on air quality is affected by the breakdown caused by the pandemic episodes, but it is more than probable that air pollutants (solid ones but also it is a main carrier for the corona virus Covid-19, causing deaths or illness, or at least an influence can be checked and proved [1].

Indoor air was believed to be a major environmental factor for more than a hundred years; still in Romania indoor air quality (IAQ) legislation is not very clear. Scientists express their opinion, based on real correlations, that the risks to health and professional damages are greater due to exposure to long term air pollution indoors, rather than to outdoors air quality, as in door concentrations are usually long term and also sometimes higher (concentrated locally) than outdoors.

Many of us spend up to 90\% of the lifetime indoors - at home, at work, at gym, at school or in transportation units or shops, restaurants, etc. The quality of the air one breathes indoors has a direct impact on the health. In poorly ventilated dwellings, emissions of PM2.5, and other pollutants can be 100 times higher than WHO-recommended levels. Particularly this recommendation specifies that emissions of PM2.5 should not exceed 0.23 mg/min when unvented (i.e. without a chimney or hood) and 0.80 mg/min when vented (i.e. with a chimney or hood). For carbon monoxide should not exceed, according emission rate targets (ERT), the value
of 0.16 g/min for unvented devices and 0.59 g/min for vented devices [2]. Such pollutants inflame the airways and lungs, impairing immune response and reducing the oxygen-carrying capacity of the blood. Statistics indicate that 4.3 million people die annually from exposure to household air pollutants, most perish from stroke (34 %), ischemic heart disease (26 %) and chronic obstructive pulmonary disease (22%). Pneumonia and lung cancer account for 12 % and 6 % of deaths, respectively [3].

Up to now, evidence shows [4] that air pollution at current levels in European cities is responsible for a significant burden of deaths, hospital admissions and exacerbation of symptoms, especially for cardiorespiratory disease. While the hazardous properties of many common pollutants are still under intensive research, evidence-based policies demonstrate that health protection is possible and effective. Starting from this conclusion, one stresses out that indoor air quality is to be more and more taken into consideration, as complementary cause of health affection and life standards expectation.

It may come as a surprise to many of us to learn that the air on an urban street, with medium traffic, actually could be cleaner than the air in our indoor spaces, where we spent our lifetime. Recent studies indicate that certain air pollutants may exist in higher concentrations indoors than outdoors. In the past, significantly less attention has been paid to indoor air pollution compared to outdoor air pollution, especially that caused by industrial and transport emissions. In recent years, however, the threats posed by exposure to indoor air pollution have become more visible.

Poor indoor air quality can be particularly harmful to vulnerable groups, such as children, the elderly and those with cardiovascular and chronic diseases such as asthma. Household air pollution is one of the leading causes of disease and premature death in the developing world [5].

The average adult at rest inhales and exhales something like 7 or 8 litters of air per minute. That totals around 11,000 litters of air in a day. The air that is inhaled is about 20 % oxygen, and the air that is exhaled is about 15% oxygen, so about 5% of the volume of air is consumed in each breath and converted to carbon dioxide. Therefore, a human being uses about 550 litters of pure oxygen per day [6]. The air one breathes is full of chemicals and harmful substances, including dust, soot, mould, fungi, bacteria, viruses and pollutants. However, the respiratory system has several ways to protect itself against most harmful airborne particles. Only very small particles (those of 3-5 μm in size) can reach the deep lungs. Nevertheless, contaminated air is traversing the mouth and nose tissues, and is retained there as well. Air quantity is hardly person-dependent (age, gender, height, weight, activity, fitness level, etc.). The average adult male working at a moderate activity level inhales 16.8 m$^3$N of air during an 8-hour working day [7].

Health effects from indoor air pollutants may be experienced soon after exposure or, possibly, years later. Some health effects may show up shortly after a single exposure or repeated exposures to a pollutant. These include irritation of the eyes, nose, and throat, headaches, dizziness, and fatigue. Such immediate effects are usually short-term and treatable. But because effects are similar to those from colds or other viral diseases, it is often difficult to determine if the symptoms are a result of exposure to indoor air pollution [8]. It has been identified a clear positive correlation between moving to a green city and the adoption of healthier lifestyles. The structural equation modelling results suggest that behaviors around the use of green space as well as perceptions of different green space have notable impacts on residents’ physical health. The findings illustrate systemic inequalities among private housing, rental housing and public housing typologies about the distribution of health benefits [9].

The indoor environments are the result of the interaction between the site, climate, construction techniques, building materials and furnishings, moisture processes, activities taking place within the building, outdoor sources, ventilation systems and behavior of building occupants (i.e., smoking, painting, etc.).

Indoor environments represent a mix of outdoor pollutants prevalently associated with vehicular traffic and industrial activities, which can enter by infiltrations and/or through natural and mechanical ventilation systems, as well as indoor contaminants, which originate inside the
building, from combustion sources, emissions from building materials and furnishings, central heating and cooling systems, humidification devices, moisture processes, electronic equipment, products for household cleaning, pets, and the behavior of building occupants [10].

IAQ can be affected by various pollutants, including gases (i.e., carbon monoxide, ozone, radon), Volatile Organic Compounds (VOCs), particulate matter and fibres, organic and inorganic contaminants, and biological particles such as bacteria, fungi, and pollen.

Pollutant sources include outdoor contaminants from traffic and industry, which enter from infiltrations and/or through natural and mechanical ventilation systems, and indoor contaminants, which are originated within the building, from combustion sources (such as burning fuels, coal and wood, tobacco products and candles), emissions from building materials and furnishings, central heating and cooling systems, humidification devices, electronic equipment, products for household cleaning, pets and individuals. It should be also considered that it is difficult to manage the control of IAQ and provide a full list of pollutants and sources applicable to all indoor environments.

The impact of these pollutants on human health may show up after single or repeated exposure episodes and will depend not only on their concentration, toxicity and exposure period but also on the synergic effect of different pollutants. Moreover, the level of indoor pollution is of critical importance for the conservation and preservation of vulnerable materials (i.e., art works, books, documents) in heritage and historic environments.

Volatile organic compounds (VOC), acrolein, formaldehyde, nitrogen dioxide (NO2), respirable particulate matter (PM-4.0 and PM-2.5) and their respective benz(a)pyrene contents were determined over a period of two weeks. Time-weighted average concentrations of NO2 (4.9–17.4 µg/m3) and formaldehyde (2.5–6.4 µg/m3) were similar on all indoor and outdoor locations. Chemical IAQ was primarily driven by known indoor sources and activities [11].

Other health effects may show up either years after exposure has occurred or only after long or repeated periods of exposure. These effects, which include some respiratory diseases, heart disease and cancer, can be severely debilitating or fatal. Also, it is very important to stress out that, according to health status, age, lifestyle, and other influencing parameters (mostly unknown) are essential. People react very differently to exposure to indoor air pollutants [12].

The literature [13] indicates for living as best solution for the future the active houses. Thus, two simultaneously results are occuling:

(i) An active house creates healthy and comfortable indoor conditions for the occupants, ensuring a generous supply of daylight and fresh air. Materials used have a neutral impact on comfort and indoor climate.

(ii) An active house is highly energy efficient. All or most of the energy needed is supplied by renewable energy sources integrated in the building or from the nearby collective energy system and electricity grid.

Considering the climate change effects, it is much more probable that due to unfavorable meteorological conditions, such as elevated ambient temperature, high relative humidity, and natural events such as dust storms, people will spend a substantial amount of their time in indoor environments [3].

The researchers have investigated 123 modern homes (test group: with mechanical ventilation; control group: naturally ventilated) built in the years 2010 to 2012 in the same geographic area and price range. Inhabitants of energy-efficient, mechanically ventilated homes rated the quality of indoor air and climate significantly higher [14].

2. Experiments and Results

Figure 1 presents the variation of different particle species, measured by a special Portable Laser Aerosolspectrometer and Dust Monitor (Model 1.108 GRIMM instrument) [8]. It possesses an integrated gravimetric filter on which all particles are collected after the optical measurement and thus are available for further analysis. It was mounted at the level of a worker at his
workplace in the printing house. The new generation instrument can be used wherever dust mass or particle number is relevant. For example, this includes the interior air quality in buildings and vehicles, dust exposure at the workplace according to EN 481 with high time resolution or also indication measurements of particulate matter in outdoor air [15].

Classic concentrations were measured by a standard gravimetric instrument – a Sven Leckel LSV3 monitor [8]. The results presented were recorded in a packaging hall. It is obvious that the more reduced the particles’ sizes are, the concentration is higher, and effects upon human health can develop in time. Also, the recorded data show that the maximum admitted value (in Romania 10 mg/m$^3$ according HG No.1218/06.09.2006, HG No 355/2) is exceeded.

**Figure 1.** Variation of the particle concentration, in a packaging industrial hall and view of the instrument location in the industrial hall [8]

![Figure 1](image1)

**Figure 2.** Concentration of PM$_{10}$ in different locations, expressed in micrograms/m$^3$, and view of the instrument location in the industrial packaging hall [8]

![Figure 2](image2)

Presently, multi-function VAC (ventilation and air conditioning) measuring instrument equipped with intelligent, digital probes which are calibrated independently of the hand-held instrument are used for simultaneous measuring of IAC [16].
Figure 3 presents the results obtained in a greenhouse during a summer episode (July 2020). The WBGT (Wet Bulb Globe Temperature) is very important for the evaluation of heat workplaces affected by heat, based on ISO 7243 / DIN 33403-3, consisting of globe, ambient temperature and wet bulb temperature probes, plug-in head cables, tripod and case (Figure 3 right).

Thermal well-being for people is established when air temperature, air humidity, air flow and thermal radiation in the surroundings are experienced at their optimum level. The Testo instrument offers sophisticated measuring instruments and probes for thermal comfort level measurement according to DIN EN 13779 and ISO 7730. The international standard ISO 7730 combines all the parameters in the PMV/PPD measurement (Predicted Mean Vote/Predicted Percentage Dissatisfied). The PMV is an index which predicts the average climate assessment value of a large group of people. The PPD Index provides a quantitative prediction of the number of people that will be dissatisfied with a certain ambient atmosphere [17].

By exception the starting points (interval), one concludes that the CO₂ ppm-level and the air velocity in m/s are quite around of a mean value (400 ppm, respectively of 0.1 m/s). The CO₂ concentration is a primary indicator of indoor air quality. Poor air quality due to excessive concentrations of CO₂ can cause tiredness, lack of concentration and even illness. Therefore, the CO₂ concentration should normally not exceed 1000 ppm. But the temperatures behaviours (both humid and dry) are varying and the velocity as well, proofing the close interdependence between the parameters. The measurements are important and essential both for the indoor climate necessary for the greenhouse plant production, and for the working personnel as well. As this greenhouse was opened only at one of it’s edges the air velocity is insignificant here as shown in the graph.

The draught temperature (the orange line) compared to the humidity temperature (yellow) is lower by only a few degrees, whilst the humidity is 40 % in average which would not be too high but taking into consideration the temperature which is around 40 degrees it’s not recommended to work on long term.

Testing of measurement values at fresh air 350 to 450 ppm CO₂ (urban air up to 700 ppm CO₂).

Our values of ppm carbon dioxide are between 380-582, most of the values being here around 400 which can be considered fresh air.

Proof of gas and leakage localization on gas pipes and installations in indoor and outdoor areas are also extremely important, as they are vital for the life, by avoiding free explosions. One
used the TESTO316-EX instrument (Gas detector with EX-protection), which conforms to the guideline 94/9/ EG (ATEX). The term ATEX comes from French being an abbreviation of the expression, „ATmosphère Explosive” which means explosive Atmosphere. This is a directive that establishes the structural requirements of a system or measuring instrument with the potential source of ignition that could cause an explosion [18]. The used instrument is a multi-range gas detector with Ex protection for the gases methane, propane and hydrogen. The gas concentrations are measured by the semi-conductor sensor in the ppm range and are shown in the display with a resolution of 1ppm. An example of the instrument used in household conditions is presented in Table 1. The scope was to depict the time in which gas leak can turn into a disaster, as CH₄, C₃H₈ and H₂ are very explosive. The values recorded are associated to different time intervals (seconds), but the values are relevant, indicating how dangerous the gas leakages in household are. The measurement example was performed with Testo-316 EX on 03/July/2020 (Figure 4).

![Image](image_url)

**Figure 4.** Pollutant dangerous explosive gas detection with Testo-316 EX on under household conditions

**Table 1.** Results attesting the high values of explosive gases in household

| CH₄ concentrations, in ppm | C₃H₈ concentrations, in ppm |
|---------------------------|----------------------------|
| 35                        | 196                        |
| 858                       | 246                        |
| 937                       | 297                        |
| 4000                      | 3000                       |
| 6000                      | 5000                       |
| 9000                      | 8000                       |
3. Conclusions
The paper reveals examples of IAC measurements, both in industrial, productive areas, but also in household conditions. They are very important for the indoor air quality, that influences both production but are essentially for the working conditions, as health can be affected. The research is based on special ace studies carried out in different industrial areas, as well in household conditions. Measurements must continue to improve the data base and support further development in the area, not mentioning the legislation, at EU and Romanian level.

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