Monitoring of the Inorganic Pollutants in Built Indoor Environment

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The paper presents the results of the monitoring of the inorganic gaseous pollutants such as nitric oxide (NO), sulfur dioxide (SO_2), ozone (O_3), carbon oxides (CO, CO_2), from indoor air of four office spaces, located in urban area of Bucharest – Romania, by using the equipment that detected and recorded, in real time, the concentrations of the compounds. The study aimed to obtain useful information on air quality from office spaces, and for the awareness of acute necessity for action to improve the quality of the indoor environment in which we live and work.

Keywords: inorganic pollutants, indoor air quality, office spaces

In urban areas, industrialization and economic growth has resulted a dramatic increase in the number of office buildings, manufacturing units, and residences simultaneously with the rise in both the number and density of motor vehicles [1], and this has led to a profound deterioration of air quality [2-3]. The increasing of the particular interest among scientists, health professionals and regulators in indoor air quality is primarily fueled by the fact that most people spend the majority of their time in different interior spaces (i.e. offices, homes, restaurants, vehicles, etc.) and this has a critical impact on their health [1, 4-6, 7-11, 16, 24, 25]. During this period, they are exposed to an ample range of pollutants, because the built indoor environment is characterized by a plurality of generation sources of chemical pollutants to which is added the contribution coming from the outside. The chemical reactions that can take place between different chemical pollutants, gaseous and/or liquids, lead to occurrence the phenomenon known as *sick building syndrom*e (SBS) [9]. Factors acting on the generation of the chemical pollutants in indoor air of the built environment are the indoor climate, the existence of sources of contamination (finishing materials, furniture parts, processes and activities inside such as cooking, heating, smoking, cleaning, and walking, etc.) [1, 12-13, 16] and the presence of occupants, all contribute to lower indoor air quality. The pollution, meaning among other things, the presence and persistence in atmosphere of some inorganic pollutants like NOx, CO, CO_2, O_3, SO_2 and other, directly affects the human health [10-12] and produces environmental modification [11]. Pollutants in indoor spaces have mixture of both outdoor and indoor sources [1, 3, 14], outdoor pollutants infiltrating readily into interior spaces through open windows, doors, and ventilation systems of the buildings. It is well established that a number of pollutants occur indoors at levels that exceed those outside [15-17].

Numerous epidemiological studies have shown that indoor air pollution is associated with a wide range of health effects, but more often air pollutants directly affect the respiratory [6, 12, 17-19] and cardiovascular systems [6, 8, 20]. Generally there are two types of health effects that are caused by indoor air pollutants, i.e. short-term effects (acute) and long-term effects (chronic). Short-term health effects such as irritation of the eyes, nose, throat, skin, headache, dizziness and fatigue [16, 20] occur after a single exposure or repeated exposures, while long-term effects appear only after long or repeated periods of exposure to indoor air pollutants [21]. For example, short-term effects of inhaling smoke from combustion inside can be irritation, inflammation and acute respiratory infections [7, 22-23] and long-term effects are chronic obstructive pulmonary disease, chronic bronchitis, allergies [24], asthma [6, 12, 24-29], atopic dermatitis [24], effects on the reproductive system and problems during pregnancy such as stillbirths or low birth weight [30] and lung cancer [24, 31]. Taking into account the multiple and complex effects of indoor air pollution on human health, initiation of a study, that to assess the current status of indoor air quality of the office spaces by identifying, qualitatively and quantitatively, inorganic pollutants such as nitrogen oxides (NO, NO_2), sulfur dioxide (SO_2), ozone (O_3), carbon oxides (CO, CO_2), has become extremely important, the aim being to raise awareness of their existence and the need for action for the improving of the air quality.

Experimental part

Three different office spaces recent renovated and a non-renovated office space, located in single-floor building from the urban area of capital of Romania, Bucharest city, were selected for the purpose of measurements. Number of occupants, spaces dimensions, the orientation and type of finishes were different, and in the first three offices, do not smoke and smoke in the fourth. The measurements have been done in normal working conditions, and the ventilation of the indoor environments was natural, through semi-open windows, when it was necessary. The concentrations of inorganic gaseous pollutants were monitored in five sampling points of the office spaces, at one meter from walls, except the office space 4, where the measurements were performed in a single point during three days. The sampling height, of 120cm from the floor, the average sampling time of the compounds (NO, O_3, SO_2), of six hours per day, and the sampling interval of five minutes were constant in all four office spaces. CO, CO_2, temperature and relative humidity were monitored an hour per day, in each space. A summary of the characteristics of the office spaces analyzed in the present experimental study is presented in table 1.

To collect the data relating the concentrations of nitrogen oxides, sulfur dioxide, ozone, carbon oxides and parameters of indoor air (temperature and relative humidity), specific measurements have been done, by recording of these in real time, using Gray Wolf Direct Sense equipment. Nitrogen oxides, sulfur dioxide, ozone and carbon monoxide has been recorded using Gray Wolf Direct Sense TG-501

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Table 1
CHARACTERISTICS OF THE MONITORED OFFICE SPACES

	Office 1	Office 2	Office 3	Office 4
Identification	Recent renovated (less than four months) non-smoking	Recent renovated (less than four months) non-smoking	Recent renovated (less than four months) non-smoking	Non renovated and smoking
Orientation	South	South	South	West
Volume(m^3)	133.17	125.82	71.27	54.77
Area (m^2)	34.5	32.60	18.45	14.19
Type of finishes	Water-based paint for walls , PVC carpet for floor	Water-based paint for walls , ceramic tiles for floor	Water-based paint for walls , PVC carpet and carpeting for floor	Water-based paint for walls, parquet flooring
Type of joinery	Wood			
Number of occupants	Four + visitors	Two + visitors	One + visitors	One + visitors
Equipments	Office furniture, four computers, four printers	Office furniture, two computers, two printers, a photocopy machine	Office furniture, a computer, a printer	Office furniture, a computer, a printer
Type of ventilation	Natural			

equipment, based on electrochemical principle, in range 0 – 250ppm for nitrogen oxides; 0 - 30ppm for sulfur dioxide; 0 – 1ppm for ozone and 0 – 500ppm for carbon monoxide. Carbon dioxide and the parameters of indoor air have been recorded using Gray Wolf Direct Sense IQ-610 equipment, with sensors based on NDIR (Non-dispersive infrared) principle for carbon dioxide, in range 0 – 10000ppm, by thermal resistance Pt100 principle for air temperature, in range -10 to +70°C, and by capacitive principle for air relative humidity, in range 0 to 100 %. The equipment can display the concentrations in ppm, ppb and ìg/m^3 units. The calibration of the equipment was performed before the start of the measurements.

Results and discussions

NO, O_3 and SO_2 concentration values (range: minimum-maximum, standard deviation-SD and median) monitored during the experimental study are presented in the table 2 for office 1, 2 and 3, and in the table 3 for office 4. The average concentrations for each inorganic pollutant in all five sampling points from analyzed office spaces are represented in figures 1, 2 and 3.

In ambient air, the *nitrogen oxides* are formed by various combinations of oxygen and nitrogen at high temperatures during the combustion process. The higher the combustion temperature, the more *nitric oxide* (NO) is generated. Indeed, 90–95% of the nitrogen oxides are usually emitted as nitric oxide and only 5–10% as nitrogen dioxide (NO_2), although substantial variations from one source type to another have been observed. In ambient conditions, nitric oxide is rapidly oxidized in air to form nitrogen dioxide by available oxidants (such as oxygen, ozone and VOCs) and this rapid oxidation velocity is such that it is nitrogen dioxide that is usually considered as a primary pollutant. In indoor air, however, this oxidation process is generally much slower [32]. Nitrogen oxides in indoor air can be provided

Table 2
MONITORING OF THE INORGANIC POLLUTANTS IN OFFICES 1, 2 AND 3

Pollutants/ Values, µg/m^3	Office 1			Office 2			Office 3		
	Range conc.	SD	Median	Range conc.	SD	Median	Range conc.	SD	Median
Point 1									
NO	9.2 – 41.8	7.0	18.1	0.2 – 0.4	0.1	0.2	1.1 – 13.2	3.0	3.6
O_3	0 – 2.5	0.4	0.5	0.01-14.5	3.5	0.3	0.14-1.65	0.27	0.53
SO_2	-	-	-	2575.7-3450.7	263.7	2874.8	-	-	-
Point 2									
NO	0.7-20.9	5.5	2.8	9.3-20.6	3.0	15.2	22.6-41,7	4.4	32.6
O_3	0.01-6.69	1.31	0.02	0.07-32.2	6.03	2.39	0.34-3.62	0.54	0.78
SO_2	-	-	-	-	-	-	-	-	-
Point 3									
NO	0.2-57.3	10.3	3.2	0.1-26.9	6.6	8.2	0.4-21.5	5.9	6.3
O_3	0.01-0.22	0.04	0.03	0.0-14.71	3.8	2.3	0.02-9.22	2.21	1.97
SO_2	-	-	-	1527.1-3061.8	357.4	2586.5	1200.8-2887.2	433.5	2449.3
Point 4									
NO	2.7-34.3	6.5	10.4	0.1-0.3	0.1	0.1	5.6-19.5	3.8	13.3
O_3	0.01-0.53	0.11	0.21	0.53-18.31	3.78	1.67	0.89-3.73	0.72	2.15
SO_2	-	-	-	-	-	-	-	-	-
Point 5									
NO	0.1-2.7	0.8	0.2	0.1-0.4	0.1	0.1	0.4-66.3	20.2	20.3
O_3	0.01-0.14	0.04	0.01	3.95-30.31	8.24	15.43	2.94-18.16	5.46	13.84
SO_2	-	-	-	-	-	-	431.1-3076.9	593.6	3011.7

Table 3
MONITORING OF THE INORGANIC POLLUTANTS IN OFFICE 4

Pollutants/ Values, μg/m^3	1st day single point			2nd day single point			3rd day single point		
	Range conc.	SD	Median	Range conc.	SD	Median	Range conc.	SD	Median
NO	3.2-16.9	4.1	6.2	15.2-70.2	14.2	18.8	28.2-70.2	10.3	44.8
O_3	0.47-1.31	0.24	0.72	0.25-13.39	3.56	1.44	0.05-13.39	1.30	2.28
SO_2	-	-	-	2277.9-2995.3	174.7	2361.6	0.0-2381.7	0.0	2381.7

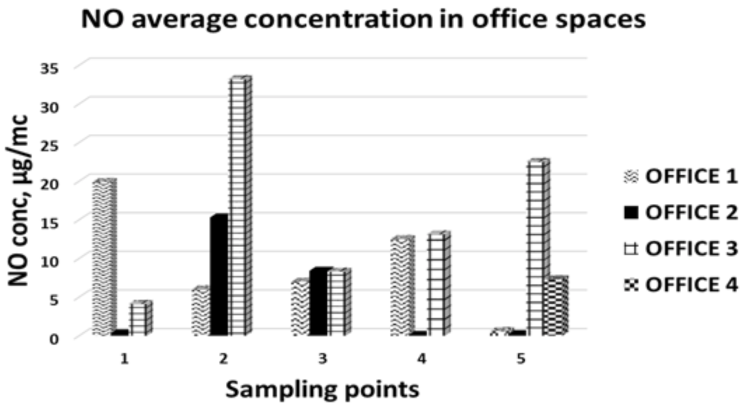

Fig. 1 Variation of NO average concentration in sampling points from office spaces

from inside or outside sources. The most important indoor sources include tobacco smoke and gas-, wood-, oil-, kerosene- and coal-burning appliances such as stoves, ovens, space and water heaters and fireplaces [7]. Inhalation is the major route of exposure to nitrogen oxides. There is recent evidence suggesting that children with atopy or asthma, infants who are at risk of developing asthma, and female adults are more sensitive to the respiratory effects of nitrogen oxides exposure [9]. An increase in indoor nitrogen dioxide of 28μg/m^3 was associated with a 20% increased risk of lower respiratory illness in children [24]. Indoor exposure to nitrogen dioxide may also enhance asthmatic reactions to inhaled allergens [9].

Relating to NO levels from our study, the range of maximum concentration was between 20.9μg/m^3 and 66.3μg/m^3 in offices 1 to 3, recent renovated and non-smoke occupants. The highest values were observed in points 1 and 3 for offices 1 and 2, and in point 5 for office 3. These points were next to the windows which have assured the natural ventilation, so it is assumed that the concentration of NO comes from outside. For the office 4, non-renovated and with smoke-occupant, the highest value of NO concentration was of 70.2μg/m^3, the potential source of this being the cigarette smoke. The average values recorded in the segment of office spaces are greater than, for example, those recorded in a space of a museum, but at the level of a printer industry [8].

Ozone is a product resulting from the photochemical reactions involving nitrogen dioxide and volatile organic compounds. Even in very small quantities, ozone is potentially harmful to human health. Acute exposure to O_3 produces decrements in pulmonary function and exercise capacity and induces airways inflammation in both healthy individuals and those with pre-existing airways disease (asthma, chronic obstructive pulmonary disease [9]. The concentration of ozone in the indoor air depends on a number of factors, including the concentration of outside ozone, the air exchange rate, the rate of emission from within the reaction between ozone and other chemicals from the air. Main sources of indoor O_3 are from outdoor O_3 resources and as well as air purifiers (electrostatic precipitous, negative ion generators and ozone generators), which are used to reduce odours and destroy microbes, and particularly in office spaces, electronic equipment such as computers, photocopiers and laser printers. There were studies on ozone emissions from these types of sources [8], being observed variations in quantities of between 16-131μg/copy before maintenance compared with 1 to 4 μg /copy after maintenance.

The O_3 maximum level in our experimental study has varied between 6.69μg/m^3 and 32.2μg/m^3 (0.003-0.018ppm) in offices 1 to 3, being the highest in the points less affected by the activities from offices. In the office 4 the maximum value of O_3 concentration was 13.39μg/m^3, less than in the other offices. All recorded values are lower

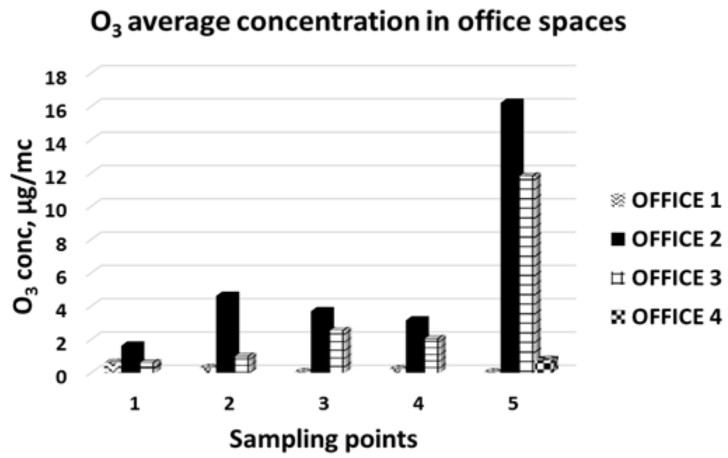

Fig. 2. Variation of O_3 average concentration in sampling points from office spaces

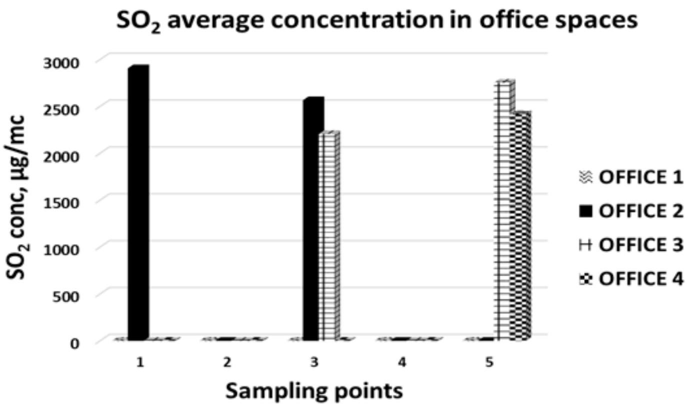

Fig.3 Variation of SO_2 average concentrations in sampling points from office spaces

than the values from other studies (221-238 μg/m^3) [8] or the values established by the US EPA (0.08-0.12ppm) [9, 33].

Sulphur dioxide is a primary combustion product of fossil fuels that can be grouped together with acid aerosols and particles to form a complex group of distinct air pollutants associated with a wide range of adverse health effects, including short-term respiratory morbidity and mortality [9]. SO_2 concentrations in ambient air range from 1-5ìg/m^3 in remote areas to 400μg/m^3 in polluted areas. Primary psychological response to exposure to SO_2 is bronchial constriction, leading to decreased lung function. On the other hand, it was noted that during the concentrations of 5ppm (13.150 mg/m^3), significantly decreases the production of antibodies [24].

For the SO_2 concentration, in this study, the maximum recorded values were between 2887.2μg/m^3 and 3450.7μg/m^3 (1.10-1.32ppm), in point 1 for the office 2 and in point 5 for office 3, meaning the points next to a gas supply source. In office 1 there is not a source so any SO_2 concentration. In the office 4, the highest value of SO_2 concentration was of 2995.3μg/m^3, the cigarette smoke being the main potential source. All recorded values of SO_2 concentration were higher than the mentioned values in other similar studies (47μg/m^3) [10] or the values established by the US EPA (0.03ppm, annual arithmetic mean) [9].

In the table 4 the range concentration values of CO, CO_2 and the values of the temperature and relative humidity recorded in all four offices are presented.

Carbon monoxide (CO) is a toxic gas, odorless and colorless, resulting from incomplete combustion processes. Carbon monoxide pollution occurs when combustion gases are discharged properly or are not re-engaged in the interior. The interior built environment, major sources of contamination by carbon monoxide are mainly related to smoke. Carbon monoxide is highly toxic, the route entering the body by inhalation, and could combine with hemoglobin in the blood, which leads to reducing the amount of oxygen in the body. The degree of occurrence characteristic symptoms (headache, fatigue, nausea, rapid breathing, and chest pain) depends on the health and sensitivity of each individual so specific response to a given concentration varies between occupants. Burnett et al., [34] found that CO, compared to the other major gaseous pollutants was the strongest predictor of elderly patients being hospitalized for congestive heart failure. The maximum values for carbon monoxide concentrations found in analyzed office spaces ranged between 0.7 and 1.4ppm and its are comparable to the data in other studies (0.74-4.69ppm in [31]), and it stands in acceptable limits as specified by OSHA – PEL, where the admissible mean value for this compound was 50 ppm.

Carbon dioxide (CO_2) is a colorless, odorless gas and is a constituent of atmospheric air at 330-350 ppm concentrations. The presence of carbon dioxide in indoor air of the built environment provides important information on the rate of ventilation air. Inside, carbon dioxide is generated primarily through human metabolism and of combustion processes resulting from activities in the kitchen or when used different space heating systems. It was observed that at a concentration above 1.5%, it produces effects on respiration process, this being hindered. The concentration maximum values of carbon dioxide in all monitored offices, between 888 and 1668ppm, exceeded the limit established by the Occupational Safety & Health Administration (OSHA) - PEL (800 ppm), being higher than the recorded values in similar studies [31]. According to the scientific literature [35] increased indoor CO_2 levels in excess of 1000ppm are closely related to occupant complains of sick-building symptoms including drowsiness, eye, nose and respiratory irritation. It can observe that in our study the offices 1 and 2 all recorded values of the CO_2 concentration exceed the value of 1000ppm, while in office 3 the average and median concentration are higher than 1000ppm, so it is possible for the occupants of these offices, in the near future, to complain by the mentioned symptoms. The parameters which can significantly affect the occupant comfort are the temperature and relative humidity. From this point of view, the highest average value for air temperature (28.3°C) was recorded in office no. 2, in the same time with a significant decrease of relative humidity average value (21.9%). A level of relative humidity below 25% is associated with an increase of the occupants discomfort and a long-term exposure in such conditions may causes problems associated with skin dryness or irritation. Generally, in the office spaces, a low value of relative air humidity can increase the static electricity, which causes occupants discomfort and block the proper operation of

Table 4

MONITORING OF THE PARAMETERS/POLLUTANTS IN ALL OFFICES

Pollutants/ Parameter	Office 1			Office 2			Office 3			Office 4		
	Range conc.	Ave/ SD	Median	Range conc.	Ave/ SD	Median	Range conc.	Ave/ SD	Median	Range conc.	Ave/ SD	Median
CO_2 (ppm)	1305/ 1577	1428/ 67	1428	1066- 1668	1428/ 208	1483	803- 1729	1157/ 337	1002	800- 888	838/ 35	817
CO (ppm)	0.6- 1.2	0.9/ 0.1	0.9	0.4- 1.4	0.9/ 0.3	0.9	0.3- 1.1	0.6/ 0.3	0.5	0.3- 0.7	0.5/ 0.1	0.5
Temp (°C)	24.1- 26.9	25.8/ 0.8	25.8	25.4- 31.3	28.3/ 1.5	27.9	20.4- 27.3	24.7/ 2.2	25.1	23.9- 27.5	25.7/ 1.1	25.6
UR (%)	29.7- 37.7	33.7/ 1.9	33.8	15.0- 31.5	21.9/ 5.1	21.5	15.7- 33.1	25.4/ 0.4	27.4	24.1- 35.2	29.1/ 3.4	29.4

computers and auxiliary equipment (copiers, printers, etc.).

Conclusions

In the modern era, across the world, there is growing public awareness regarding the risk associated with poor indoor air quality (IAQ) in the workplace and home. Gases such as nitrogen oxides (NOx), ozone (O_3), carbon monoxide (CO) and sulfur dioxide (SO_2) and passive smoke are among common types of air pollutants encountered indoors [9]. On average, a person carries out around 75,000 professional work hours in a lifetime. Good working conditions are therefore vitally important, not only for personal well-being, but to ensure that employees remain both health and productive. In our study we have determined the inorganic gaseous pollutants concentrations such as NO, O_3, SO_2, CO and CO_2, in the indoor air of four office spaces, located in single-floor building from the urban area of Bucharest, Romania. The complexity of inorganic compounds effects on human health has been primary criterion of the choice. NO maximum concentration levels were between 20.9$\mu g/m^3$ and 66.3$\mu g/m^3$ in offices 1 to 3, recent renovated and non-smoke occupants. The O_3 maximum level has varied between 6.69$\mu g/m^3$ and 32.2$\mu g/m^3$ (0.003-0.018ppm) in offices 1 to 3. For the SO_2 concentration, the maximum recorded values were between 2887.2$\mu g/m^3$ and 3450.7$\mu g/m^3$ (1.10-1.32ppm), in offices 2 and 3. The maximum values for carbon monoxide concentrations found in analyzed office spaces ranged between 0.7 and 1.4ppm, while the concentration maximum values of carbon dioxide, in all monitored offices, ranged between 888 and 1668ppm. Selected results have been given with the specific aim to compare them with existing guidelines for indoor air quality as specified by the US EPA, OSHA or WHO and to evaluate them against other previous studies. Indoor environment quality involves regulating the climate inside buildings and workplaces, in addition to acting upon reports from employees/tenants on health conditions, indoor temperature, ventilation levels and other concerns. The volume of obtained results in this experimental study completes and develops the concept related to indoor air quality, a domain of great interest on European level and worldwide.

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