

Experimental Studies on TVOC Concentrations and their Relationships with Indoor Comfort Parameters

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Indoor air quality (IAQ) remains a very important issue because it can significantly affect people's health, comfort and productivity. Volatile organic compounds (VOCs) comprise an important group of chemicals that are commonly present in indoor air. They are related to the sick building syndrome (SBS) and exposure to VOCs is of considerable concern due to their potential chronic and acute health outcomes which includes eye irritation, nose and throat discomfort, headache, allergic skin reaction, nausea, fatigue, or dizziness. Most of the times the effects of VOCs on human health are amplified by indoor conditions such as temperature and humidity. The paper presents the findings of the analysis of the relationship between total volatile organic compounds (TVOC) concentrations and their influencing factors like indoor comfort parameters (temperature and relative humidity) and the type of indoor spaces (offices, residential and educational).

Keywords: TVOC concentrations, indoor comfort parameters, Pearson correlation coefficients

Many efforts have been made, during the last decades, to protect populations from harmful exposure to outdoor pollutants, networks of air monitoring stations being located in strategic places in order to provide information on the pollutant concentrations to which humans are exposed [1]. However, people spend more than 80% of their time in various indoor spaces (i.e. homes, offices, educational, etc.) [2-6] and the quality of indoor air, is an important factor influencing human health. Indoor air pollution is widely recognized as one of the most serious potential environmental risks to human health. The World Health Organization recognized indoor-air pollution as the 8th most important factor for health and responsible for 2.7% of the global burden of diseases. Indoor air quality (IAQ) remains a very important issue because it can significantly affect people's health, comfort, satisfaction and productivity [7-8]. Volatile organic compounds (VOCs) comprise an important group of chemicals that are commonly present in indoor air and constitute one of the main sources of indoors pollution [9]. These compounds are described by its main physical characteristics such as boiling range and vapour pressure, the most referenced being benzene, toluene, ethylbenzene and xylene (BTEX), polyaromatic hydrocarbons (PAHs) and formaldehyde [10].

There have been many studies on air pollution in urban areas [11-14] and their transport to buildings [15-18], but fewer studies have been conducted on VOCs. However, the effects of VOCs on human health show that their importance is not at all lower and it has to cause of concern firstly due to their role in formation of ground level ozone and smog, and secondly due to some of them being carcinogenic, mutagenic and teratogenic in nature [7]. Exposure to VOCs is also of considerable concern due to their potential chronic and acute health outcomes [2, 19-20]. Key signs or symptoms associated with exposure to VOCs include eye irritation, nose and throat discomfort, headache, allergic skin reaction, nausea, fatigue, or dizziness. VOCs are produced by anthropogenic activities such as transport or industry, and by biogenic activities of plants [1, 10], but also various materials such as carpets, wallpaper, curtains, paper products, and electronic equipment release VOCs, with newer materials emitting highest concentrations. Most of the times the effects of VOCs on human health are amplified by indoor conditions such as temperature and humidity [21]. VOCs could be at the base of various discomforts inside the buildings and lead to what is called sick building syndrome (SBS) in scientific literature [4, 22]. Understanding the evolution of TVOCs concentration inside buildings is the basis for predicting this variation and a correct ventilation strategy for interior spaces.

In our study we propose to answer in this new research direction, related to the explanation of the variation of the indoor concentration of TCOV. Thus, the main objective of this paper is to analyze, by monitoring and statistical interpretation, the correlation between TVOC concentrations and other comfort parameters simple to determine as temperature – θ and relative humidity - ϕ under monitoring conditions, for different type of spaces (offices, residential and educational), located in urban area of Bucharest city (fig.1). Basic statistics and correlation analysis were applied in the analysis data.

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Experimental part

Spaces description

The studies were performed in spaces with different types of activities, located in districts 2 and 3 of urban area of Bucharest, the largest city and the capital of Romania (fig.1).

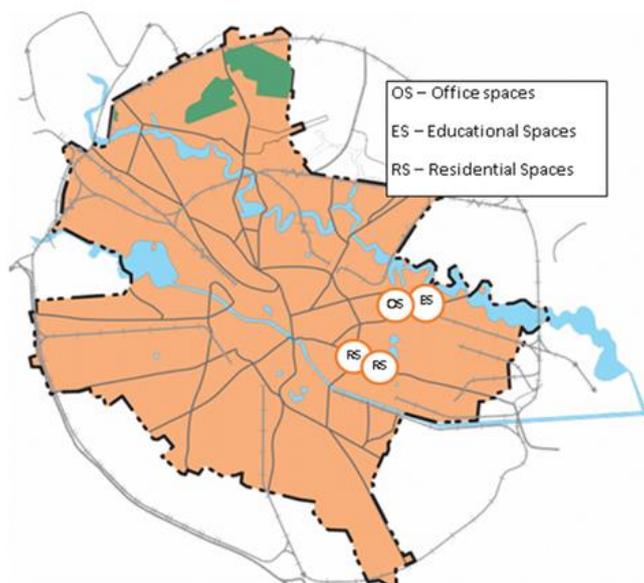


Fig.1 Locations of the monitored spaces from Bucharest city

The investigated segment of the monitoring activity consisted of three office spaces, three residential spaces (bedrooms and kitchens) and six educational spaces (two kindergartens, three general schools and a high school). First test segment, consisted of three office spaces with drawings presented in fig. 2, is located upstairs of the building.



Fig.2 Drawings of the monitored office spaces (OS)

The walls of all three offices are polished using aqueous dispersion paint and the floor is covered with glazed tiles in OS1 and OS2, respectively PVC carpet in OS3. The windows and doors of the OS1 and OS2 are made of PVC profiles. OS3 has PVC windows and plywood door. The measurements were performed in normal operating conditions of the spaces, and from time to time the number of residents may vary as persons may temporarily leave or enter the office. The fresh air is provided exclusively by infiltration/exfiltration and natural ventilation rate is occasionally increased by temporarily opening the mobile elements of building envelope.

As pollutants from exterior sources can affect the interior air quality [22-23], the residential spaces (RS) that were investigated from the point of view of indoor air quality were selected based on the area where they are located, being selected a building located relatively far from the traffic (RS1) and a building located next to a high traffic boulevard (RS2 and RS3). Interior spaces (with drawings in fig.3) were chosen on the assumption that in the kitchen areas there are many sources of emissions and the resting area (bedroom) is the most importance space, where emissions should be minimized. Pollutant concentration measurements were performed in situ, both in the absence of inhabitants and in the case of them carrying out normal activities, while the space ventilation was of natural type.

RS1 is an apartment in a four levels building. The windows are made of PVC profiles with double glazing and the doors are wooden made. For the decoration of bedroom (RB1) walls interior waterborne paint was used and the floor is made of solid wood flooring. The kitchen (RK1) has both walls and floors finished with glazed ceramic tiles. RS2 (RB2 and RK2) are located at second floor and RS3 (RB3 and RK3), at ninth floor of the building. The windows are

made from AL and PVC profiles and the doors are wooden made. The waterborne paints were used for decoration of wall bedrooms and the glazed ceramic tiles for walls and floors of kitchens.

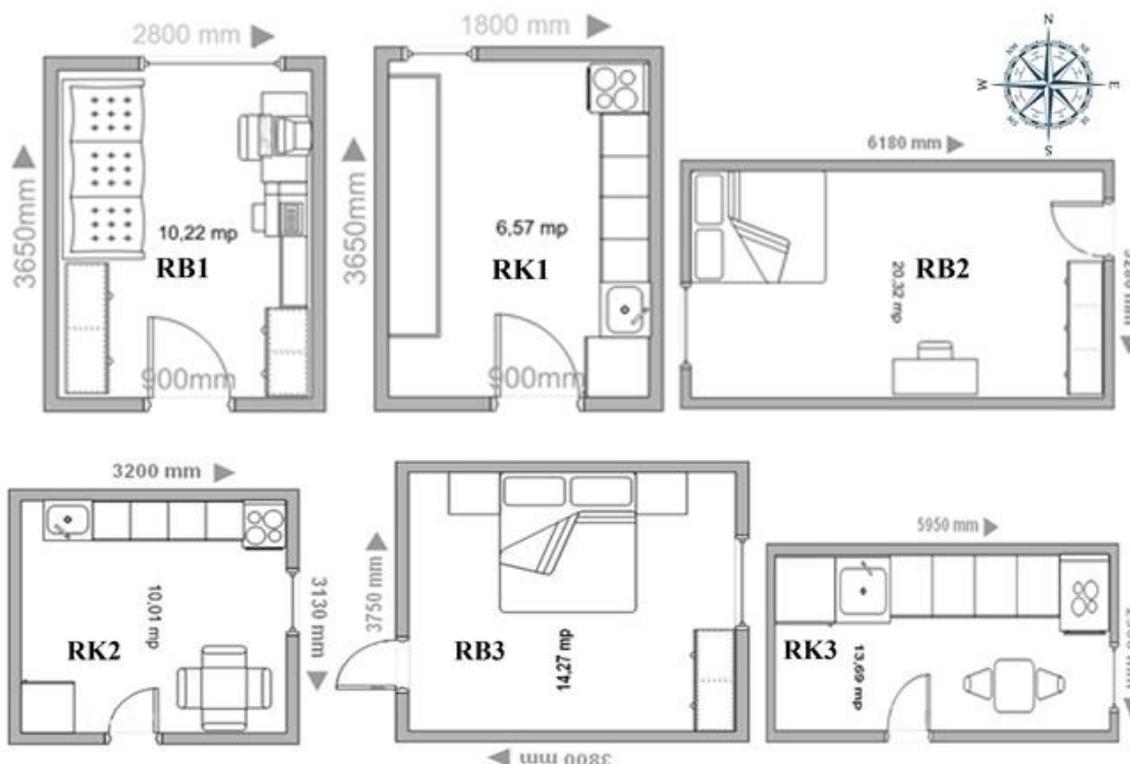


Fig.3 Drawings of the monitored residential spaces (bedrooms, RB, and kitchens, RK)

The investigated educational spaces (ES) consisted of two kindergartens (ES1 and ES2), three general schools (ES3, ES4 and ES5) and a high school (ES6), where children from 3 to 17 years of age perform daily activities. The walls of the ES were finished with white-colored water dispersion, and the flooring was made of laminate flooring. The windows and doors are made of PVC profiles.

Instrumentation

The measurement of TVOC concentrations, C_{TVOC} , in ppm, was performed using a direct detection method and the portable data-logging detector IQ-610 probe (GrayWolf Sensing Solutions, USA), in range 20 – 20000ppb, with a resolution of 1ppb. The operating principle is based on electronic detection, having a photo-ionization detector (PID) sensor, consisting of a light source (lamp) with a specific potential ionization measured in electron volts (10.6 eV). The equipment has inside sensors, thermal resistance Pt100, for the measurement of the temperature, θ , °C, between -10°C and +70°C, with a precision of $\pm 0.3^\circ\text{C}$ and of the relative humidity, ϕ , %, (using capacitive principle), between 0 and 100%, with a precision of $\pm 2\%$. The equipment was calibrated before the measurements.

Experimental program: The experimental program is presented in table 1.

Table 1
CHARACTERISTICS OF THE EXPERIMENTAL PROGRAM

Characteristic	Type of space		
	Office spaces	Residential spaces	Educational spaces
Sampling height above the floor level, m	1.20	1.20	1.20
Sampling interval, min	5	5	1
Daily measurement period	09:00 am – 01:00pm, working days	16:00 pm - 20:00 pm weekdays and weekend days	1 hour weekdays
Sampling point	center of the room	center of the room	located in the area behind the classroom, 1 meter away from the wall
Monitoring campaign period	March - May 2012	August - September 2013	October 2015
Simultaneous recording of TVOC concentrations, temperature and humidity			

Results and discussions

The obtained values in OS, represented in fig.4, vary from 0.17ppm to 0.3ppm ($390.1\div 688.5\mu\text{g}/\text{m}^3$ isobutylene units), the values from RS between 0.1ppm to 0.38ppm ($229.5\text{--}872.1\mu\text{g}/\text{m}^3$ isobutylene units), and in ES from 0.34ppm to 1.11ppm ($780.3\text{--}2,547.3\mu\text{g}/\text{m}^3$ isobutylene units). It can observe that the lowest values were obtained in

RB1, 0.1ppm, and in OS2, 0.17ppm, and the highest values were obtained in ES, particular in two of general schools, 1.1ppm in ES3, and 1.1ppm in ES5.

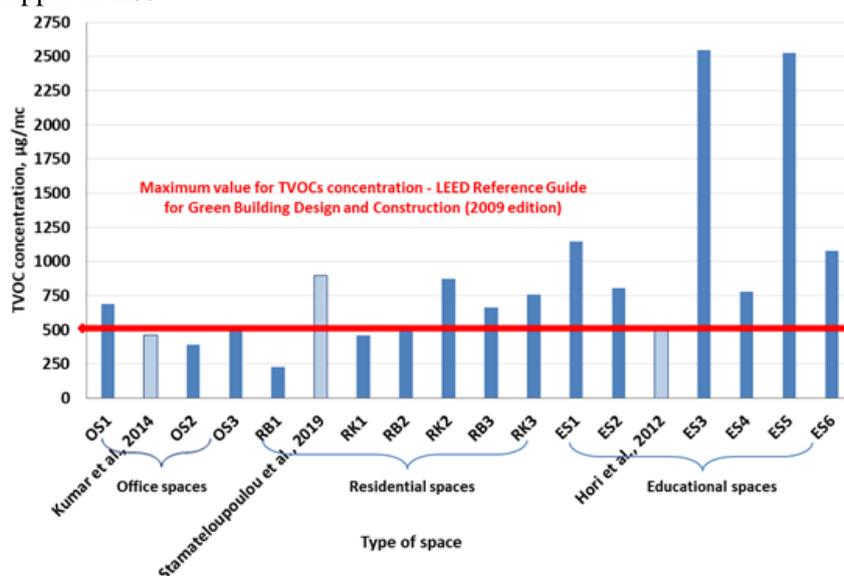


Fig.4 TVOC concentrations (average values) in investigated spaces

Our results are comparable with the similar studies conducted internationally. A recent article [2] reported the mean concentration of TVOC as $465.8\mu\text{g}/\text{m}^3$ ($145.3\div 1503.2\mu\text{g}/\text{m}^3$) in winter and $321.8\mu\text{g}/\text{m}^3$ ($90.7\div 1,100.9\mu\text{g}/\text{m}^3$) in summer for indoor air of the library of Jawaharlal Nehru University, New Delhi, a range of 100 and $538\mu\text{g}/\text{m}^3$ for TVOC concentrations was reported in indoor air of some Japanese University classrooms [24]. Sarkhosh and colleagues [25] measured the concentrations in range from 113.4 to 486.3ppb ($227\text{--}973\mu\text{g}/\text{m}^3$ isobutylene units) in photocopy centers and Chan and colleagues [26] recorded TVOC concentrations in new hotels' guest rooms of the factory region which varied between 416 and $2900\mu\text{g}/\text{m}^3$. Recently, Stamateloupoulou et al. [27] reported the concentrations of TVOC in range from 24 to $890\mu\text{g}/\text{m}^3$ in residences with young children, and Liu et al. [28], the mean TVOC concentrations of $89.7\mu\text{g}/\text{m}^3$ in underground parking garages with traffic volume. It is interesting to mention that the maximum value for TVOCs concentration, given in the LEED Reference Guide for Green Building Design and Construction (2009 edition), is of $500\mu\text{g}/\text{m}^3$ (for measurements in a minimum period of 4 hours).

From the point of view of temperature, represented in fig.5, the highest values are registered in RS, between 25.2°C and 30.1°C , following by the values from ES, between 24.6°C and 28.7°C , the both higher than the guideline levels ($23.5\div 25.5^\circ\text{C}$) of the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE), and the lowest values are in OS, from 22.3°C to 23.1°C , under the limits of ASHRAE.

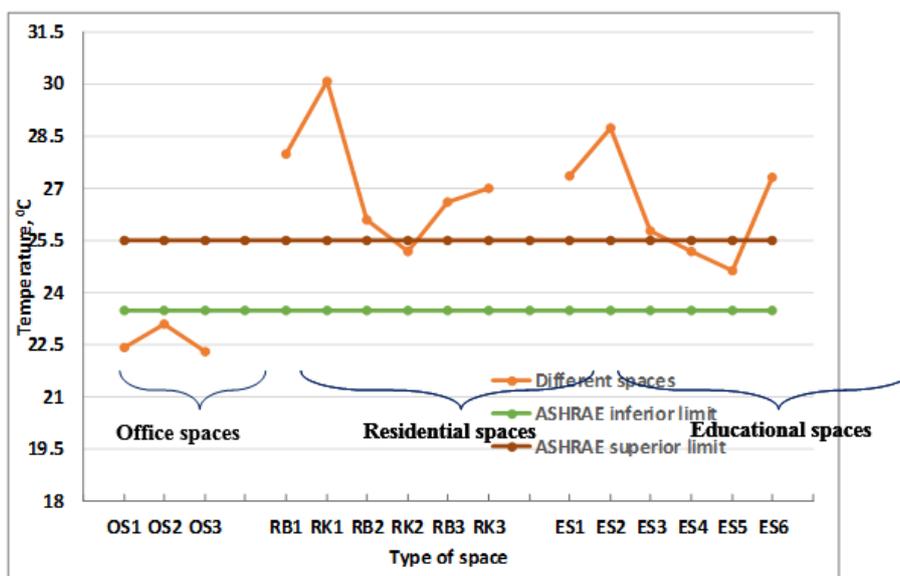


Fig.5 Average Indoor Temperature during TCOV measurements campaign

The values of relative humidity, represented in fig.6, are in range of 29.5% and 36.9% for OS, between 44.5% and 54.1% for RS and from 37.9% and 58.6% for ES, the highest values, but in limits ($30\div 60\%$) indicated by the guideline levels of the ASHRAE. The lowest values were registered in the OS, while the highest values both in RS and ES.

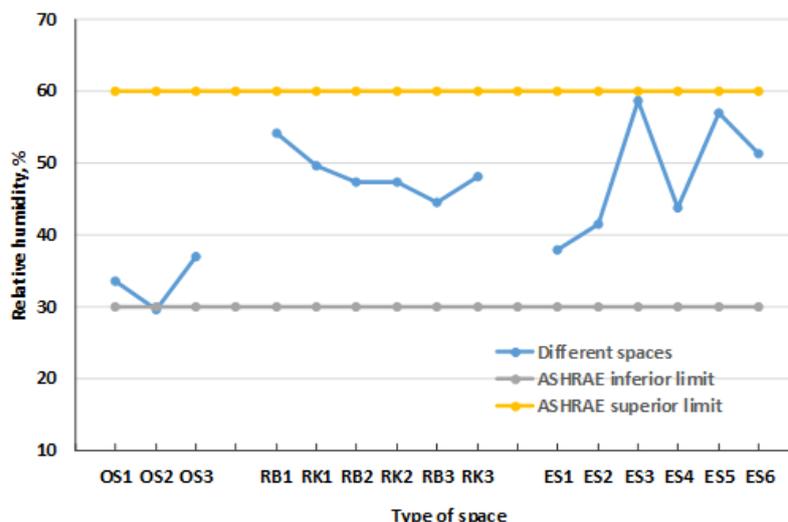


Fig.6 Average Indoor Relative humidity during TCOV measurements campaign

In order to answer of new research direction, respectively the explanation of the variation of the indoor concentration of TCOV with indoor comfort parameters – temperature and relative humidity, in fig.7-8 are represented, for example, the relationships between them, for OS and RS (RK).

As it can see from fig.7a, there is an inverse correlation between TVOC concentration and temperature, a strong one for all office spaces and, respectively, no correlation for RS (RK), in fig.7b.

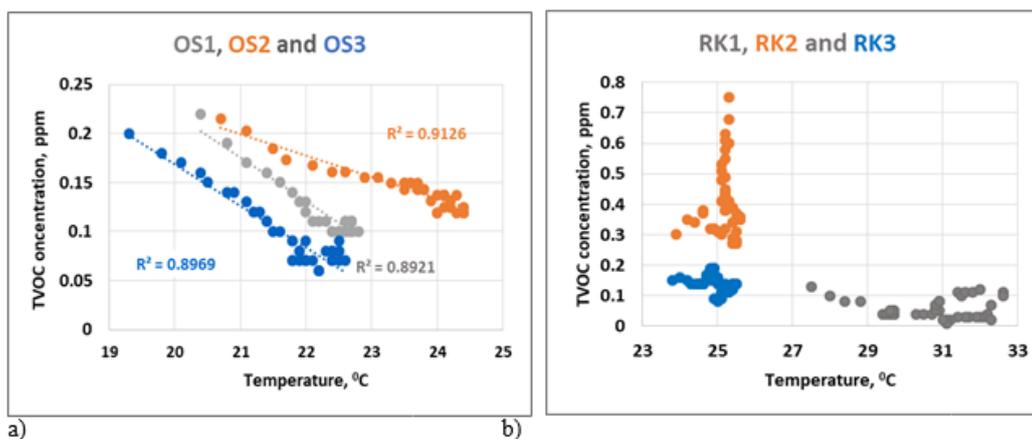


Fig.7 a) Inverse correlation C_{TVOC}/θ for OS; b) No correlation C_{TVOC}/θ for RK

Between TVOC concentration and relative humidity, as it can see in fig.8a, there is a direct correlation, a stronger correlation for offices OS2 and OS3, and, respectively, no correlation for RS (RK), in fig.8b.

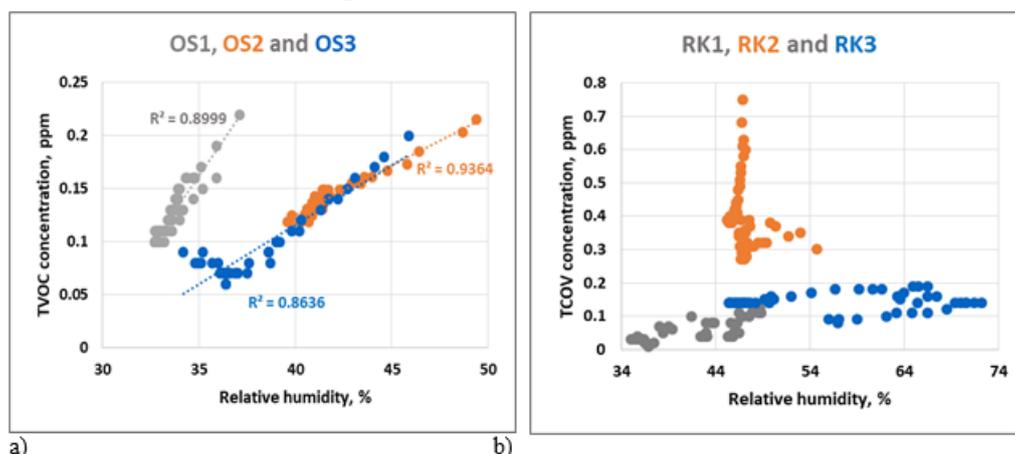


Fig.8 a) Direct correlation C_{TVOC}/φ for OS ; b) No correlation C_{TVOC}/φ for RK

The correlations between TVOC concentration and the environmental parameters (temperature and relative humidity) are varied in scientific literature. Thus, the direct correlations between TVOC concentration and relative humidity are confirmed by other previous studies, such as Tao et al. [29], while the inverse correlation between TCOV concentration and temperature, by Adebayo et al. [7]. The inverse correlation between temperature and relative humidity is confirmed by Bucur et al. [21] and other studies [11, 30].

In order to better understand if the TVOC concentration and the analyzed parameter vary simultaneously or not, we have calculated the Pearson correlation coefficient. This coefficient is calculated as the ratio between (1) the covariance of the TVOC concentration and the analyzed parameter and (2) the product of the standard deviations of the TVOC concentration and the analyzed parameter. The correlation coefficient varies between -1 and 1, which means that when is close to zero then there is no correlation between the two parameters and when it is close to the limits of this interval then the two parameters are correlated (the sign “+” indicates a direct correlation and both parameters increase or decrease simultaneously) and the sign “-“ indicates there is an inverse correlation – when one parameter increases the other one decreases). The obtained values of the Pearson correlation coefficients for TCOV concentration and temperature (C_{TCOV}/θ), TVOC concentration and relative humidity (C_{TCOV}/ϕ), temperature and relative humidity (θ/ϕ) in the investigated spaces are presented in table 2.

Table 2
PEARSON CORRELATION COEFFICIENTS FOR THE INVESTIGATED SPACES

Analysed space	Correlation coefficients, ρ (-)		
	$C_{TVOC} - \theta$	$C_{TVOC} - \phi$	$\theta - \phi$
OS1	-0.958	0.948	-0.827
OS2	-0.956	0.967	-0.971
OS3	-0.947	0.929	-0.964
RB1	-0.652	0.915	-0.884
RK1	-0.046	0.636	-0.556
RB2	0.295	0.214	-0.030
RK2	0.040	-0.238	-0.813
RB3	-0.492	0.571	-0.981
RK3	-0.251	0.069	0.828
ES1	-0.962	0.899	-0.958
ES2	-0.949	0.967	-0.955
ES3	-0.839	0.898	-0.951
ES4	-0.166	0.951	0.106
ES5	-0.883	0.995	-0.922
ES6	-0.847	0.918	-0.830

As it can see in the table 2, for all OS there is a great inverse correlation between TCOV concentration and temperature (C_{TCOV}/θ), and between temperature and relative humidity (θ/ϕ), while between TVOC concentration and relative humidity (C_{TCOV}/ϕ) there is a great direct correlation. The same, for ES, except for ES4, where is confirmed the direct correlation between TVOC concentration and relative humidity. In RS it is a different situation, especially in RK where, mainly because of cooking activities, the correlations found in other spaces are not valid. Temperature has already been found to significantly influence the formation of other outdoor and indoor pollutants [11, 30].

The obtained mean values of the Pearson correlation coefficients for TCOV concentration and temperature ($C_{TCOV} - \theta$), TVOC concentration and relative humidity ($C_{TCOV} - \phi$), temperature and relative humidity ($\theta - \phi$) in the investigated spaces are presented in figure 9 a, b and c.

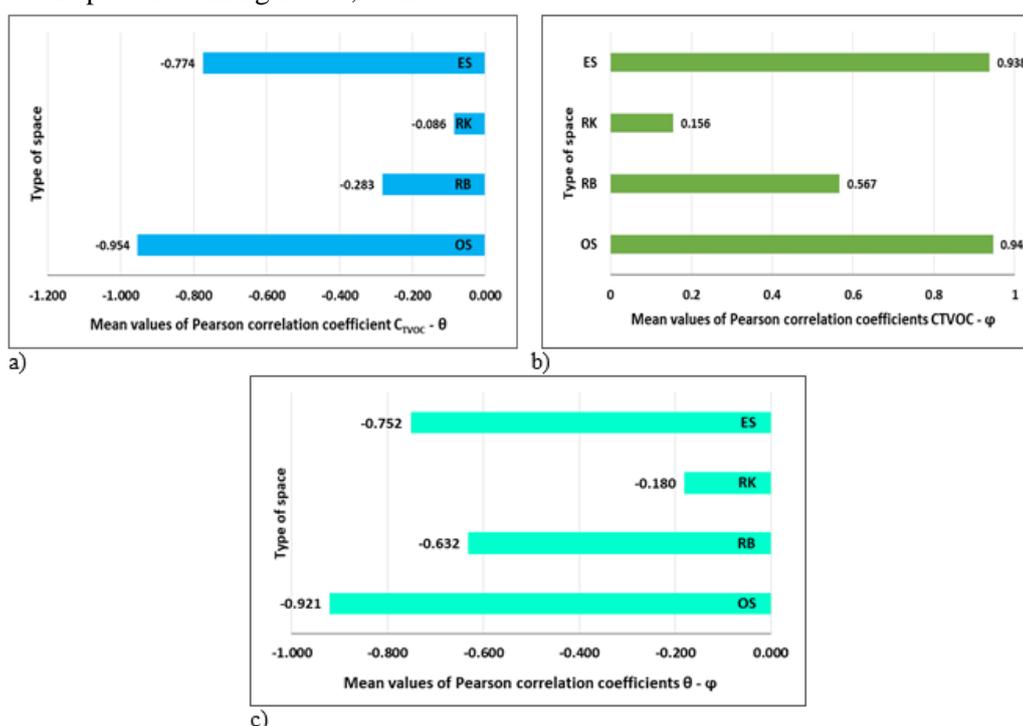


Fig.9 Mean values of Pearson correlation coefficients

The mean values of Pearson correlation coefficients, represented in fig.9, show the strong inverse correlation between TVOC concentrations and temperature and a strong direct correlation between TVOC concentrations and relative humidity in OS and ES. But in RS, especially in the RK, there is not a correlation between the TVOC concentrations and the indoor comfort parameters – temperature and humidity.

Conclusions

The paper presents the obtained results, by monitoring and statistical interpretation, of the correlation between TVOC concentrations and environmental parameters (temperature and relative humidity) in different type of spaces (offices, residential and educational), located in urban area of Bucharest city.

The TVOC concentrations varied from 0.17ppm to 0.3ppm (390.1–688.5 $\mu\text{g}/\text{m}^3$ isobutylene units) in office spaces, between 0.1ppm to 0.38 ppm (229.5–872.1 $\mu\text{g}/\text{m}^3$ isobutylene units) in residential spaces, and from 0.34ppm to 1.11ppm (780.3–2,547.3 $\mu\text{g}/\text{m}^3$ isobutylene units) in educational spaces, being the highest ones. From the point of view of temperature, the highest values are registered in residential spaces, between 25.2°C and 30.1°C, following by the values from educational spaces, between 24.6°C and 28.7°C, the both higher than the guideline levels (23.5–25.5°C) of the ASHRAE, and the lowest values are in office spaces, from 22.3°C to 23.1°C, under the limits of ASHRAE. The values of relative humidity, are in range of 29.5% and 36.9% for office spaces, between 44.5% and 54.1% for residential spaces and from 37.9% and 58.6% for educational spaces, the highest values, but in limits (30–60%) indicated by the guideline levels of ASHRAE.

The Pearson correlation coefficients showed that for all office spaces there is a great inverse correlation between TCOV concentration and temperature (C_{TCOV}/θ), and between temperature and relative humidity (θ/ϕ), while between TVOC concentration and relative humidity (C_{TCOV}/ϕ) there is a great direct correlation. The same, for the educational spaces, except for ES4, where is confirmed the direct correlation between TVOC concentration and relative humidity. In the residential spaces it is a different situation, especially in the kitchen spaces where, mainly because of cooking activities, the correlations found in other spaces are not valid. To avoid any health risks caused by poor indoor air quality are needed preventive measures for the reduction of effective sources. To reduce VOC levels in the indoor environment it will be necessary two type of measures: to eliminate the sources of chemicals through a better choice of construction/furnishing materials and to increase the ventilation rate.

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