Monitoring the Indoor Air Quality and Microclimate for Improving Passenger Health and Comfort Level in Bucharest Subway Platforms

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This paper presents the results of the air quality by the content of CO_2, CO, $PM_{2.5}$, PM_{10} and the microclimate (temperature and relative humidity) monitoring campaign, in Bucharest underground transport network. The monitoring was performed using both manual and automatic data acquisition systems. All the acquired data were stored in a specific database system used for fast reporting and alarming. GIS software was used to precisely locate the exterior air intakes for selected stations in order to know the quality of the exterior air circulated through them and for finding the best position for new ones. The research was conducted on different station platforms, belonging to the same line, in the Bucharest subway system throughout a year (2015) in order to improve air quality and comfort level of subway stations. The obtained results will serve as basis for improving the air quality and comfort level in the new long subway lines designed and built now in Bucharest.

Keywords: indoor microclimate, air quality monitoring, data acquisition systems, temperature-humidity index, Geographic Information System.

Subway is vital for commuting in crowded cities and it is recognized that will become more and more important over time.

According to recent studies [1-8], the comfort level, indoor air quality and security in underground transportation are a major environmental problem anywhere in the world. It is noticed that often the subway air has higher levels of air pollution than in trams or walking in the street. [3, 4] The related institutions and self-governing bodies must have continuous preoccupation to monitor, correct and make the right decisions in order to improve the subway environment current state.

In Bucharest (Romania) all subway lines and stations are exclusively underground and due to this feature the confined microclimate can accumulate different pollutants entering from the outside through ventilation systems in addition to those generated within the system by the frequency and speed of trains due to abrasion and wear of wheels, braking pads and rail tracks, caused during the motion of the trains, and subway stations and tunnels architecture.

Due to the particularities of Bucharest subway architecture, the heat and the substance flows may change several times within a year, cyclic regimes being controlled by reversing the ventilation on the winter-summer schedule. It is important to underline that subway stations make a heat transfer with the outside and vice versa.

This paper aims to conduct a study on indoor air quality in Bucharest underground transport network. The subway network consists of: 53 stations grouped in 4 lines, the total length of the network being 71.10 km of double track. In addition to the 71 km tunnel network, this subway has public and technical spaces, offices, laboratories, electrical substations, underground depots, draws, reserve lines, interstation areas for air tunnel evacuation when trains run, etc. All of these spaces greatly increase the total surface area of the underground transport network [9].

With 106 trains and over 4500 employees the network carries up to 750000 daily passengers who often lead to excessive crowding and accumulation of various types of hazardous pollutants for human health. Even in these circumstances metro's interior environment must ensure thermal, optical, acoustic and bioclimatic comfort both for operating personnel and travelers.

For this case study, it is important to define the underground environment, which is unique due to the dynamics of external and internal factors which exert major influences on underground microclimate.

According to World Health Organization, environmental risk factors play a role in more than 80% of the diseases regularly reported and at global level nearly one quarter of all deaths and of the total disease burden can be attributed to the environment [10].

Indoor air quality is directly affected by the surrounding environment through the building materials used, the type and quality of ventilation, furniture and electrical appliances, cleaning and household products, occupant habits, the degree of maintenance of the building etc. [2, 5, 11-14].

The subway environment must provide thermal, optical, acoustic and bioclimatic comfort for both operating staff and the passengers. The determining parameters for thermal comfort are air temperature and relative humidity. Thermal comfort can be achieved in the temperature range of 18-30°C and relative air humidity between 30-60% [15, 16].

The importance of indoor air temperature lies in its influence on the body's thermoregulation process. Air movement favors thermoregulation of organisms and has two parameters - speed and direction. The velocity of the air greatly influences the human body thermolysis and room ventilation. By acting on the sensitive skin receptors, air currents influence the central nervous system. In closed spaces air flows at speeds of 0.3 - 0.6 m/s may cause unpleasant sensations.

Under the conditions of comfortable microclimate, the body's thermoregulatory processes are in a balanced state. It is manifested by a comfortable thermal state, optimal central nervous system functioning, increased physical and intellectual work capacity, increased resistance to harmful factors.

In case of microclimatic discomfort, the thermo-regulation processes of the body are under the strain appearing unpleasant thermal sensation. Also, the functions of central nervous system deteriorate and the resistance to chemical and contagious agents decreases.

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Uncomfortable microclimate may be the cause of acute or chronic illness [2, 5, 17].

In order to decrease the energy consumed to maintain the thermal comfort limit measures have been taken to reduce the air flow provided by the ventilation and also to seal all the sources of thermal energy. These measures have made important financial savings, but there have been problems with indoor air quality by increasing biological and chemical pollutant levels beyond normal limits. [18]

From the point of view of hygiene, air influences health through both its chemical composition and its physical properties [2, 5].

In terms of chemical composition, influence on the health derived from variations in normal component concentration and the presence of foreign compounds in the air. A normal chemical composition of the air indicates 20.95% oxygen. Small decreases in the concentration of up to 18% are tolerated without any disturbance by the human body. From a health point of view, the concentration of carbon dioxide oscillations, substances with a special role in the exchange of gases in the lungs, are important and can be considered as an indicator of air pollution when its value exceeds 0.07% [19, 20].

Experimental part

For this case study the research was conducted on three station platforms in the Bucharest subway system throughout 2015 in order to improve air quality and comfort level of subway stations along to Line 1: Crangasi Subway Station - G.P.S coordinate: N 44°27'06.517"; E 26°02'51.719", Gara de Nord 2 Subway Station - G.P.S coordinate: N 44°27'08.43"; E 26°05'10.68" and Eroilor Subway Station - G.P.S coordinate: N 44°26'05.758"; E 26°04'32.504".

GIS software was used to precisely locate the stations and the exterior air intakes in order to know the quality of the exterior air circulated through them and for finding the best position for new ones. In order to create the geospatial maps (Figure 1), the Esri ArcGIS 9.3 platform was used to introduce geospatial coordinates obtained by identifying latitude and longitude data on site in each of the 51 subway stations.

The indoor air monitoring activity in the Bucharest subway network was simultaneously deployed in two directions throughout the year 2015, namely: microclimate - monitoring the temperature and relative humidity of indoor air that define thermal comfort and air chemistry - monitoring the concentrations of: carbon monoxide and carbon dioxide and particulate matter.

The air quality monitoring network comprises: 130 automatic monitoring devices Testo 174H, three mobile devices for collecting particulate matter and two mobile gas collecting devices (oxygen, carbon monoxide and carbon dioxide).

The automatic Testo 174H equipment has a memory capacity of up to 16.000 measurements of temperature and humidity. The measuring range is between -20 °C and +70 °C for temperature and between 0 and 100 % rH for relative humidity. Devices are located in public and technical spaces at a height of 2 meters above the ground in lattice boxes specially designed for this purpose.

The mobile devices were used for manual measurements of particulate matter and gases (oxygen, carbon monoxide and carbon dioxide).

In order to determine the carbon monoxide and carbon dioxide concentration, samples were collected using a container attached to an absorption pump positioned at a height of 1.5 meters from the ground level. The collected sample was analyzed in the microclimate laboratory using the INFRALYT 4 device in order to determine the concentration of carbon monoxide and carbon dioxide.

To determine total particulate matter concentration paper filters were used after an absorption pump positioned at a height of 1.5 meters from the ground level. After 30 min the paper filters were extracted and analyzed in the laboratory.

The sample collection and analysis diagram is presented in Figure 2.

From a functional point of view, the actual monitoring system consists of three stages: supervision, evaluation of the real status and control (Figure 3).

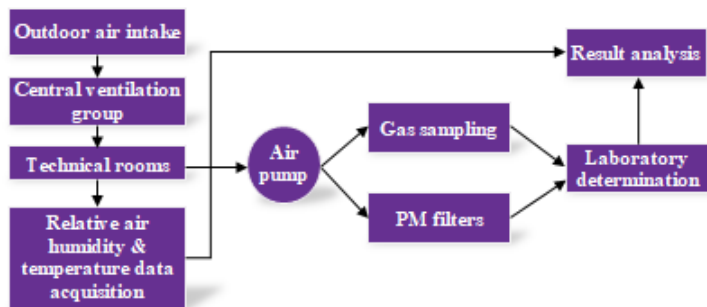Fig. 1. Bucharest Subway GIS Map

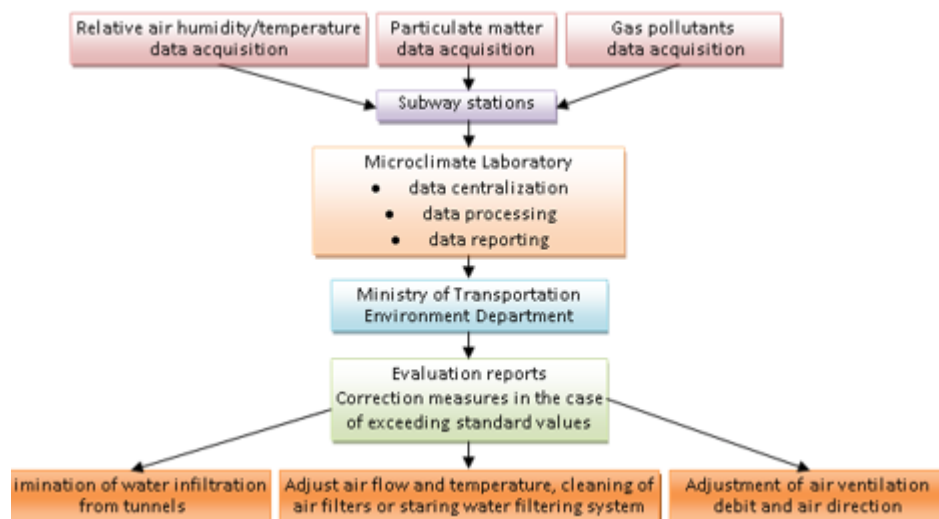Fig. 2. Sample collection and analysis diagram

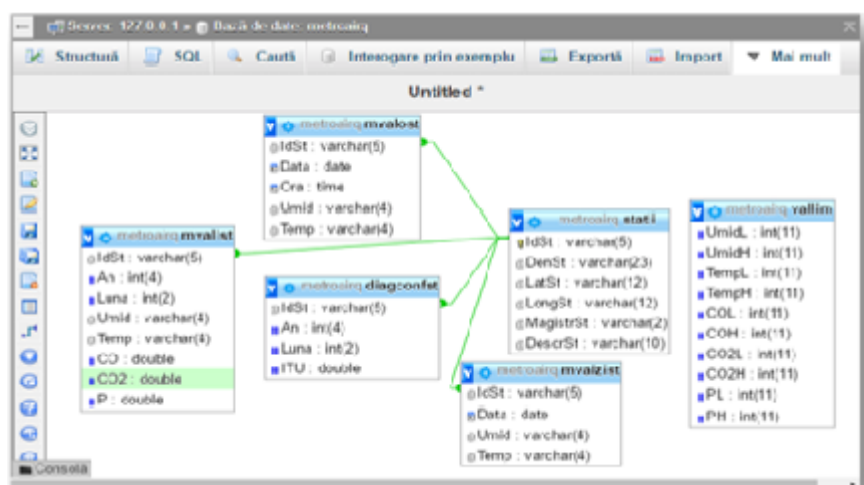Fig. 3. Metrorex monitoring and control system architecture

Fig. 4. Metroairq Database structure

All acquired data were stored in a MySQL database for a faster data reporting and processing. The database structure is presented in figure 4.
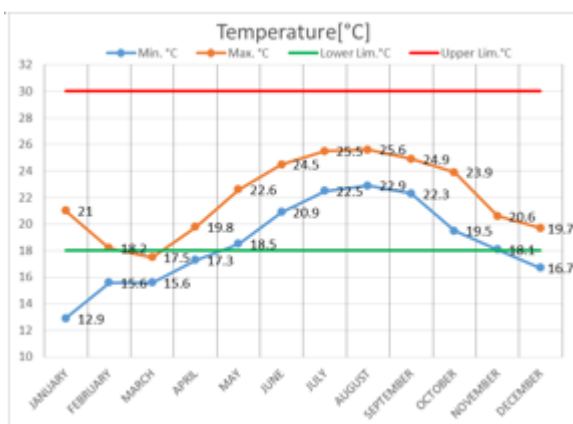

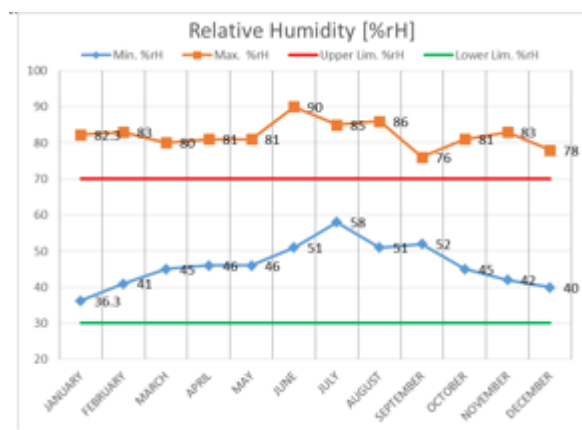Fig. 5. Minimums and maximums of monthly temperatures at Crangasi station - 2015

Fig. 6. Minimums and maximums of monthly relative humidity at Crangasi station - 2015

Results and discussions

The data acquired from the sensors was statistically treated in order to highlight the minimum, the average and the maximum monthly values. The statistical data for all three stations are presented in figures 5-22.

Fig. 7. Comfort diagram Crangasi station 2015

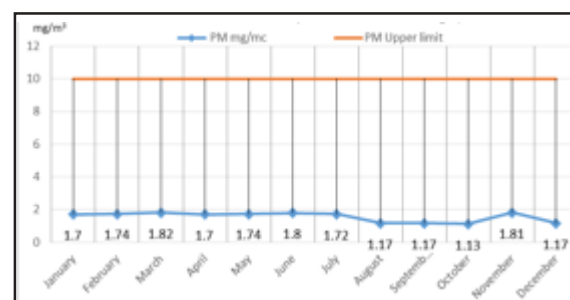Fig. 8. Carbon monoxide monthly levels 2015 Crangasi station

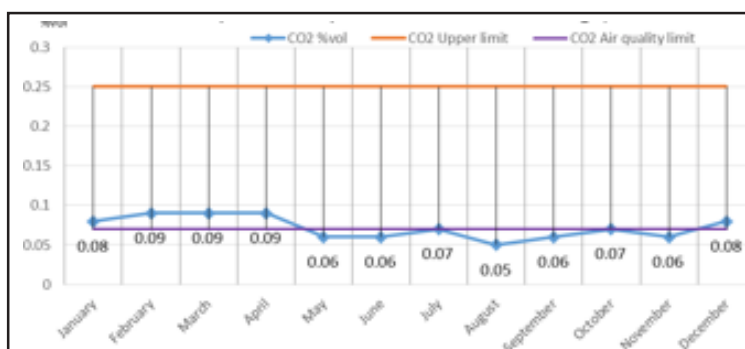Fig. 9. Particulate matter monthly levels 2015 Crangasi station
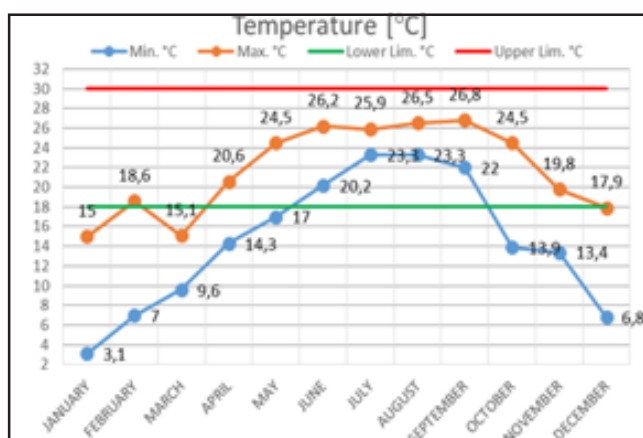

Fig. 10. Carbon dioxide monthly volume levels 2015

Fig. 11. Minimums and maximums of monthly temperatures at Gara de Nord station - 2015
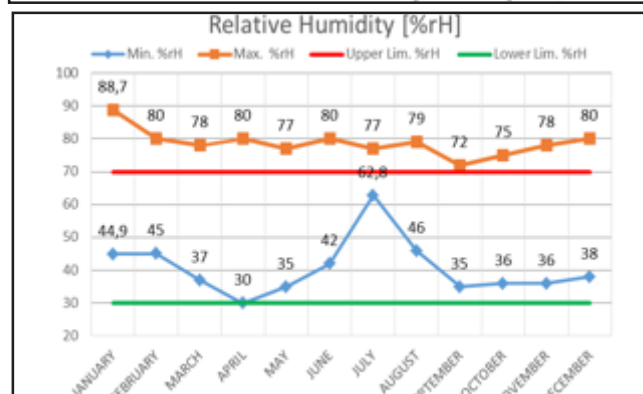

Fig. 12. Minimums and maximums of monthly relative humidity at Gara de Nord station - 2015
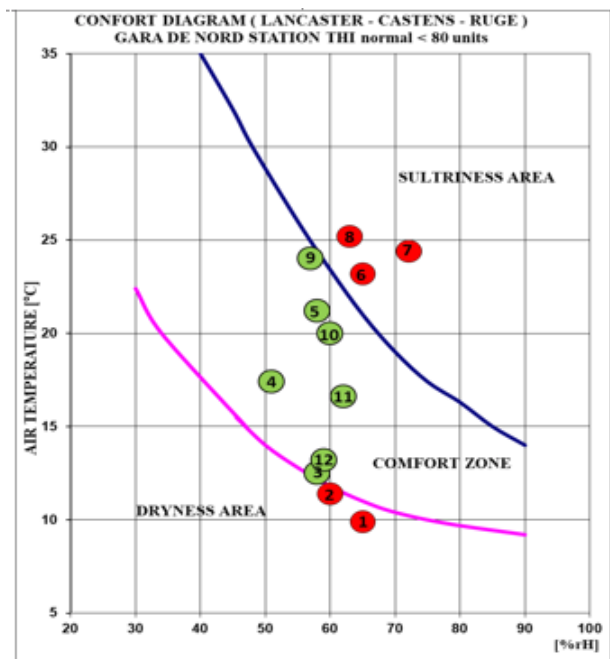
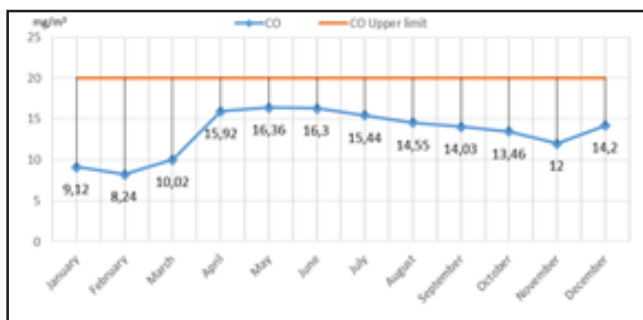Fig. 13. Comfort diagram Gara de Nord station 2015

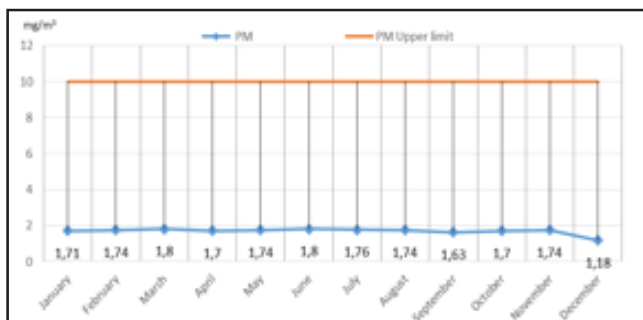Fig. 14. Carbon monoxide monthly levels 2015 Gara de Nord station

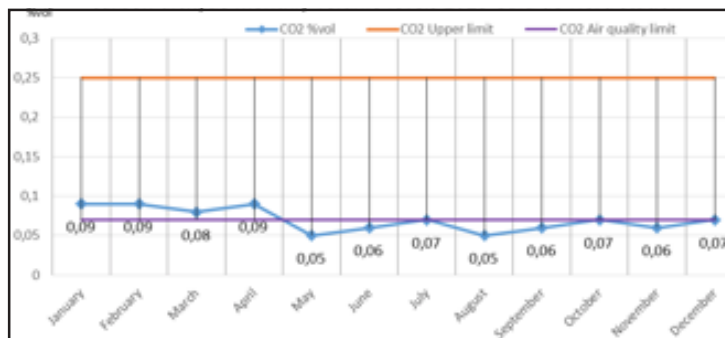Fig. 15. Particulate matter monthly levels 2015 Gara de Nord station

Fig. 16. Carbon dioxide monthly volume levels 2015 Gara de Nord station
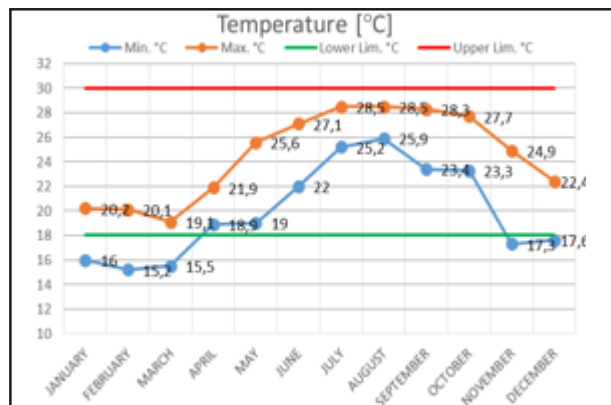

Fig. 17. Minimums and maximums of monthly temperatures at Eroilor station - 2015

Fig. 18. Minimums and maximums of monthly relative humidity at Eroilor station - 2015

Fig. 19. Comfort diagram Eroilor station 2015

In the appreciation of the thermal comfort in the subway, the Lancaster - Carstens diagram was used (Figure 7). The THI (temperature-humidity index) required for the Lancaster - Carstens diagram was calculated using the equation below:

$$THI = 0.8 * avg.T + 0.01 * avg.rH *$$
$$* (0.99 * avg.T - 14.3) + 46.3,$$ (1)

where: avg. T and avg. rH are the average values of temperature and relative humidity, respectively.

In all three monitored stations there were deviations of the THI values relative to the limits as follows:

-in Crangasi station in January, February, March, April, November and December the index fits into the comfort zone and in May, June, July, August, September and October

Fig. 20. Carbon monoxide monthly levels 2015 Eroilor station

Fig. 21. Particulate matter monthly levels 2015 Eroilor station
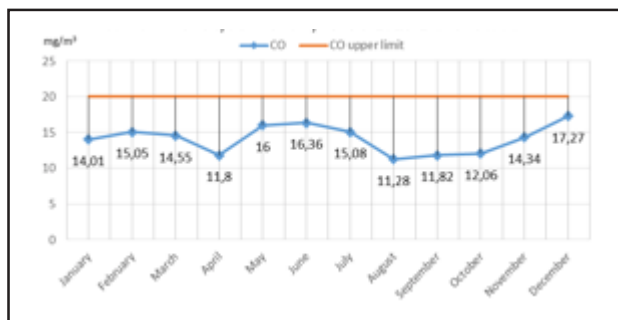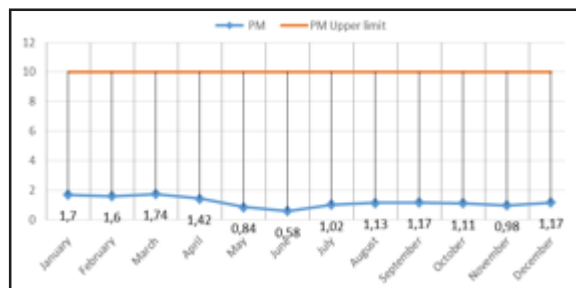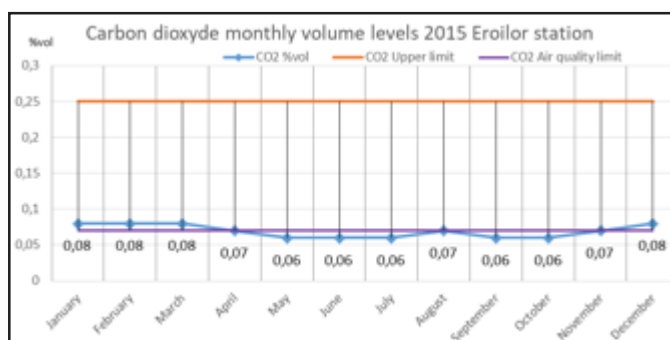

Fig. 22. Carbon dioxide monthly volume levels 2015 Eroilor station

the index leave the comfort zone and lie in the sultriness area;

-in Gara de Nord station in March, April, May, September, October, November and December the index fits into the comfort zone, in June, July, August the index leave the comfort zone and lie in the sultriness area and in January, February the index lie in the dryness area;

-in Eroilor station in January, February, March, April, May, September, October, November and December the index fits into the comfort zone and in June, July, and August the index leave the comfort zone and lie in the sultriness area.

Even if there were exceedances of one or both of the two parameters (interior temperature and relative humidity), they were short-lived and caused by extreme conditions (exterior temperatures above 35 °C or below -15 °C and external relative air humidity above 90% rH).

The carbon monoxide value in subway air for the case study stations ranges between 8.24 and 17.27 mg/m³ but never exceeded the maximum permissible limit.

The carbon dioxide value in the subway air varies between 0.05% vol. and 0.09% vol. Considering that values ranging from 0.07 to 0.1% vol. of carbon dioxide indicate the appearance of air vices, it can be concluded that frequently the air in the technical spaces of the metro is vitiated but there have been no exceedances of the admissible maximum limits of 0.25% vol.

The level of oxygen in the indoor air in the subway has never dropped below 19% vol. The phenomenon indicated by most underground workers, namely *lack of air* or *lack of oxygen*, is caused not by decreases in oxygen concentration, but by overcoming the air vitiation threshold (> 0.07% by volume of CO_2), combined with temperature and humidity variations, artificial illumination and continuous noise caused by mechanical ventilation.

The particulate matter concentration values in subway air for case study stations varies between 0.58 and 1.82 mg/m³, but has never exceeded the maximum permissible limit of 10 mg/m³ of air.

Conclusions

Creating and implementing an integrated system for monitoring and controlling installations to ensure microclimate and air chemistry in the subway can improve the quality of indoor air, can make significant power savings and provide an immediate and punctual response. Also, ventilation systems will no longer work on a permanent basis.

It is necessary to implement a database management system for coherent storage and fast reporting of monitoring results.

The flow of current information is ineffective because it is dependent on outside weather conditions for thermal comfort and the response to what the sensors record must be rapid so that there is no gap between receiving the information and making a decision.

The current data collection and interpretation system for particulate matter needs to be modernized by acquiring automatic network-connected stations that can provide real-time data to decision-makers within the environmental department.

For a better quality of air flow vehiculated through the external sockets, it is necessary to lift all ground-level inlet sockets, as they exist in many of the stations, up to 2 meters from the ground and surrounding these air intakes with vegetation curtains.

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