Indoor Air Quality Assessment in the Romanian National Aviation Museum

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National Museum of Romanian Aviation is the only museum of its kind in the country who holds in a historical succession the evolution of the Romanian aeronautics starting from Traian Vuia and Aurel Vlaicu until today. Documents, models and aircraft exhibited in the museum, many of them being unique, can be irreversibly degraded under the action of chemical air contaminants and/or inadequate microclimate conditions. The article presents the results of air quality assessment within the main exhibition space of the museum, Hangar 1, obtained in a study organized in 2014-2015. Given the specific of the museum and its location, in a city with intense traffic, both indoor and outdoor concentrations of NO_2, SO_2, CO, O_3, PM2.5 and microclimate parameters (temperature and relative humidity) were monitored. Monitoring results showed lower concentrations indoor than outdoor, I/O ratios fits in the interval [0.32; 0.8] except CO with an I/O ratio situated close to the value 1. Averages concentrations were below those recommended by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) for air chemical pollutants measured inside the museum, except ozone concentration whose average is in the hot season slightly above the recommended limit but below the lower intervention limit, 50 $\mu g/m^3$. Microclimate parameter values also fall into a range that implies reduced risk for various objects and books according to ASHRAE; diurnal variations of microclimate parameters do not represent a danger for the exhibits in the museum, also. Analyzing the information obtained by monitoring indoor air quality and statistical interpretation of these data (I/O ratios, diagrams, Spearman correlation analysis) we can say that the air inside Hangar 1 and microclimate conditions provided do not raise major problems for long-term conservation of the exhibits in the museum and do not require additional measures in terms of air quality and microclimate parameters.

Keywords: museum, indoor air, urban area, Spearman correlation, I/O Ratio

Pollution and climate change effects represents a serious problem for the protection of collections, especially for those housed in historic buildings that were not built with this destination.

Parameters that can damage the collections are: temperature (T), relative humidity (RH), illumination level, air pollution (gas and particulates) and different pests (including insects, rodents, birds). The microclimate temperature is a parameter that can generate destructive effects on materials particularly through direct effect on the exhibits but also indirectly by influencing their speed of reaction with chemical compounds in the air; an increase in temperature of 10^0C can double the speed of reaction [1]. Particularly dangerous are large diurnal variations in layers on materials such as varnished objects and veneer with inserts of wood or metal, due to phenomena of repeated expansion/contraction [2].

High relative humidity, as in case of temperature, can increases the deterioration rate of materials; 70% relative humidity increases the probability of occurrence of mold, corrosion of metal objects, and can affect glass objects. In the case of museums located in the big cities, emissions from road traffic are the main source of air pollution with compounds resulted from combustion [4-7]. Besides oxides of carbon, nitrogen and sulfur in the atmosphere we find also dust containing heavy metals, volatile metals and a wide range of organic compounds, including polycyclic aromatic hydrocarbons [8-10]. The penetration of these pollutants in the air inside museums can have particular effects on exhibits going up to their destruction.

Most of the times the effect is amplified in microclimate conditions characterized by high temperature and humidity (RH). Thus, in the presence of high humidity, the nitrogen and sulfur oxides form acids that can react with the materials that exhibits are made of, forming at their surface hardly soluble salts, unaesthetic; can react with leather objects [11] causing red spots; can corrode metals and accelerate the degradation of paper and other organic materials, including wood. Most metals, including copper, lead, silver, bronze and aluminum alloys are susceptible to corrosion in acidic medium and the effects can be irreversible [12-13]

Ozone reacts with organic materials causing change of color and discoloration of the pigment [14-15] and with compounds containing sulfur; Rubber products lose their elasticity becoming hard and brittle. Particulate matter also can generate, in the presence of moisture and some metal salts, corrosion cells that can damage the surfaces of the exhibits [16].

In this context the first step in implementing preventive conservation measures for exhibits of a museum is to assess air quality and microclimate parameters [17]. This represents the main objective we have set in this article: i) air quality and microclimate parameters assessment in the most important exhibition space of the museum, ii) identification of major sources of pollution and, if necessary, iii) recommending measures to reduce the negative impact on exhibits.

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Fig. 1. Location of the museum (a); Outdoor exhibits (b) in Hangar 1 (c) and Hangar 2 (d)

Experimental part

The experimental tests regarding the study of air quality inside museums and the effect of air pollutants on exhibits were conducted during 2014-2015 in the exhibition rooms belonging to the National Museum of Romanian Aviation. Thus, to assess air quality outside and inside the building, two campaigns of sampling/measurement were organized in the period 2014-2015, being continuously monitored the concentrations of NO_2, SO_2, CO, O_3, PM2.5 and the data obtained were: i) statistically analyzed in order to characterize data sets and to determine the correlations between indoor air parameters, ii) I/O ratio calculation and, iii) comparing the results obtained with the recommended values of regulations for protecting heritage objects from degradation due to environmental conditions.

Field sampling

National Museum of Romanian Aviation is located in the northern part of Bucharest in the hangars of the former military airfield Pipera, in an area with rich vegetation, away from the city's major traffic arteries and highly polluting industrial units (fig. 1a). The exhibition space of the museum comprises two Hangar and an outdoor exhibition (fig. 1b, c and d).

Hangar 1 (fig. 1c) houses hosting the main exhibition - aeronautics history from the beginnings to 1959 and Hangar 2 (fig. 1d) is dedicated to the period after 1960.

The exhibits are made of metal covered with pellicle coatings, wood, plastic, glass, leather and rubber. Hangars are built of brick being provided with metal access doors and windows that allow outdoor air to penetrate inside the building even when they are closed. The spaces are not equipped with air conditioning systems, ventilation being performed through open windows and doors and for heating, in the winter, the buildings are connected to the centralized heating system of the city.

Methods for chemical pollutants and microclimate parameters monitoring

For continuous monitoring of NO_2, SO_2, CO, O_3 concentrations were used Horiba automatic analyzers mounted on a mobile laboratory, coupled to a programmable switching system indoor/outdoor. To quality assurance, analyzers were calibrated periodically using calibration gas according to the standards in force: SR EN 14211/2012 [18] for NO_2, SR EN 14212/2012 [19] for SO_2, SR EN 14625:2012 [20] for O_3 and SR EN 14626/2012 [21] for CO. The analyzers are equipped with data storage systems that can be downloaded, processed and interpreted. The outdoor temperature and humidity were measured using a weather station installed on the top of the mobile laboratory, and the indoor parameter it was monitored using a GRAY WOLF analyzer. Daily average concentrations of PM2.5 particulates were determined by gravimetric method according to SR EN 12341:2014 [22]. Indoor, samplers and automatic analyzers were installed in the middle of the room and outdoor, the mobile laboratory was placed 5 meters from the building, away from the access roads. Gaseous compounds and microclimate parameters were performed hourly, and PM2.5 particulate matters, were performed daily, according with the standards recommendations.

To test the normality of data sets distribution were used numerical methods based on calculation of skewness and kurtosis indicating how much the distribution of a variable deviates from symmetrical shape. The value 0 of the asymmetry coefficient indicates a normal distribution, symmetric, and a value greater than 1 indicates a distribution that differs significantly from the normal distribution [23].

The characterization of the data sets obtained through monitoring, the type of data distribution, correlation analysis between parameters were performed using the Statistical Package for Social Sciences 20.0 (SPSS 20.0).

Air quality monitoring requirements

To assess ambient air quality were taken into account the NO_2, SO_2, CO and O_3 limit values from the Directive 2008/50/EC (table 1) and for museum indoor air the values recommended by ASHRAE Handbook - Chapter 21, 2007 for general collections [1] (table 2). For PM 2.5, the relate was done to the daily limit value set by the US EPA, 35 μg/m^3 [24], in the European legislation being established only the annual limit value.

Table 1
LIMIT VALUES IN AMBIENT AIR - Directive 2008/50/EC [25]

No. crt.	Indicator	Averaging period	Limit values, μg/mc
1	SO_2	1 h	350
2	NO_2	1 h	200
3	CO	Averages for 8 h	10.000
4	Ozon (target value)	Daily	120

Indicator	Suggested limits for collections				Intervention limits			
	Sensible materials		General collections		Urgent		Extremely urgent	
	ppb	μg/m^3	ppb	μg/m^3	ppb	μg/m^3	ppb	μg/m^3
NO_2	<0.05 – 2.6	<0.1-5.3	2-10	4-20	26-104	110-210	>260	>530
SO_2	<0.04 – 0.4	<0.1-1	0.4-2	1-5.7	8-15	23-43	15-57	43-160
O_3	0.05	0.1	0.5-5	1-10	25-60	50-130	75-250	160-530
PM2.5	-	<0.1	-	1-10	-	10-50	-	50-150

Table 2
LIMIT VALUES RECOMMENDED FOR GASEOUS POLLUTANTS (ASHRAE Handbook - Chapter 21, 2007) [1]

According to ASHRAE [1] the presence of carbon monoxide in the indoor air of the museums does not represent a danger for exhibits and there are no limit values recommended for this pollutant.

Results and discussions

To assess the air quality inside Hangar 1 were carried out monitoring in order to establish the concentrations of NO_2, SO_2, CO, O_3, PM2.5 and microclimate parameter values, both inside and outside the building, in the hot season (20-27.06.2014) and in cold season (20-27.03.2015). The monitoring results are centralized in tables 3 and 4. The evolution of the parameters are presented in figure 2 for gaseous chemical pollutants and figure 3 for temperature and humidity.

Ambient air quality

Regarding the concentration of chemical pollutants in ambient air, on average, the indicators monitored falls below the limit for population health protection for all indicators (NO_2, SO_2, CO, O_3, PM2.5) in all testing periods. One explanation can be given because the museum is located in the suburbs, at a relatively large distance from major highways and industrial platforms, surrounded by lush vegetation that cause a reduction in air pollution.

In terms of weather conditions, the values for temperature and humidity, measured outside, were within normal limits specific to the temperature during summer (temperatures between 14 and 30°C and relative humidity between 32 and 100%) respectively in winter (temperatures between 0 and 14°C and relative humidity between 23 and 100%).

These parameters can influence the microclimate inside buildings, depending on the building climate control system and its efficiency, but also depending on the insulation characteristics of the building.

Considering that the museum building is acclimatized, the influence of outdoor meteorological parameters depends on the insulation of the building, and also by the performance of the heating system, during the cold season.

The concentration of chemical pollutants in Hangar 1

Analyzing the centralized values presented in tables 3 and 4 and diagrams from figure 2 we can observe a good air quality with average values which are below the limits recommended by ASHRAE for general collections in case of NO_2, SO_2 and particulate matter PM 2.5; in the case of ozone the values are below the recommended limit of 10 μg/m^3 in cold season (9.55 mg / m^3), and slightly more

Table 3
MONITORING RESULTS AND INDICATORS OF DATA SERIES SUCH AS CENTRAL TREND, DISPERSION AND DISTRIBUTION FORMS FOR HANGAR 1 AND OUTDOOR AIR DURING 20-27.06.2014

	I- NO_2 μg/m^3	O-NO_2 μg/m^3	I-SO_2 μg/m^3	O-SO_2 μg/m^3	I-O_3 μg/m^3	O-O_3 μg/m^3	I-CO mg/m^3	O-CO mg/m^3	I-PM 2.5 μg/m^3	O-PM 2.5 μg/m^3	I-temp ^{0}C	O-temp ^{0}C	I-RH %	O-RH %
N	81	81	81	81	81	81	81	81	8*	8*	162	162	162	162
Mean	13.7736	17.7119	3.9162	4.8587	11.2605	27.7034	.2035	.1949	9.6828	22.1758	21.7881	20.9362	59.9923	69.4790
Median	11.4700	14.3800	3.7300	4.1705	11.6180	29.4545	.1947	.1834	9.4300	21.7600	21.9450	20.1350	60.2200	72.3600
Std. Deviation	6.95868	11.54222	1.01375	1.84468	1.88306	7.94397	.05406	.06849	.96343	1.81343	1.81851	4.47866	4.90694	20.01601
Skewness	2.781	1.773	1.700	1.392	-1.281	-.630	3.715	2.824	.676	.866	-.234	.289	-.016	-.246
Kurtosis	11.762	3.980	3.417	1.972	2.055	-.458	26.563	13.076	-.927	-.323	-.910	-1.062	-1.008	-1.091
Minimum	6.45	3.70	2.61	2.83	3.53	9.54	.15	.12	8.62	20.12	17.84	13.70	51.13	31.56
Maximum	58.94	64.94	7.50	11.56	13.94	39.17	.64	.64	11.43	25.76	24.88	29.89	69.39	100.20
I/O	0.77		0.80		0.41		1.09		0.44					
Max. diurnal variation											3.4		9.2	
ASHRAE [1]	4-20	-	1-5.7	-	1-10	-	-	-	1-10	-	<25	-	25-75	-
Directive 2008/50/EC[25]	-	200	-	350	-	120	-	10	-	-	-	-	-	-
US EPA [24]	-	-	-	-	-	-	-	-	-	35	-	-	-	-

Table 4
MONITORING RESULTS AND INDICATORS OF DATA SERIES SUCH AS CENTRAL TREND, DISPERSION AND DISTRIBUTION FORMS FOR HANGAR 1 AND OUTDOOR AIR DURING 20-27.03.2015.

	I- NO_2 μg/m^3	O-NO_2 μg/m^3	I-SO_2 μg/m^3	O-SO_2 μg/m^3	I-O_3 μg/m^3	O-O_3 μg/m^3	I-CO mg/m^3	O-CO mg/m^3	I-PM 2.5 μg/m^3	O-PM 2.5 μg/m^3	I-temp ^{0}C	O-temp ^{0}C	I-RH %	O-RH %
N	82	82	82	82	82	82	82	82	8*	8*	164	164	164	164
Mean	16.0308	25.0287	3.7523	5.6808	9.5521	29.9917	.4199	.4460	9.0737	18.8757	10.6268	6.9485	44.8311	65.4291
Median	15.6900	20.0800	3.6010	4.6040	9.3460	28.9773	.3976	.3786	8.9300	18.9600	10.5000	6.8335	44.8000	66.8800
Std. Deviation	4.64399	19.62002	.44191	2.43917	.72658	6.40972	.08504	.18314	.73399	.95891	1.48840	2.77856	3.07053	20.25917
Skewness	.371	1.385	2.330	1.776	2.140	.355	.625	1.860	.196	-.305	.008	.037	.035	-.112
Kurtosis	-.271	1.627	8.799	3.056	7.601	-.699	-.292	3.628	-.557	-1.380	-1.201	.044	-.781	-.827
Minimum	6.51	2.80	3.20	3.50	8.75	19.89	.30	.27	7.91	17.43	7.70	.37	38.30	22.93
Maximum	29.11	92.72	6.44	14.09	13.32	43.67	.64	1.16	10.35	20.13	13.30	13.73	49.80	100.20
I/O	0.64		0.66		0.32		0.95		0.48					
Max. diurnal variation											5.2		7.7	
ASHRAE [1]	4-20	-	1-5.7	-	1-10	-	-	-	1-10	-	<25	-	25-75	-
Directive 2008/50/EC[25]	-	200	-	350	-	120	-	10	-	-	-	-	-	-
US EPA [24]	-	-	-	-	-	-	-	-	-	35	-	-	-	-

* daily average

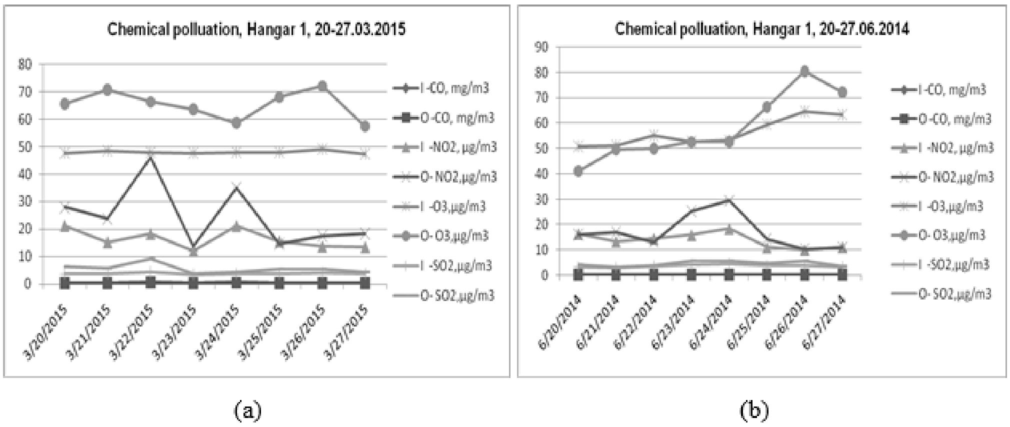


Fig. 2. Variation in time for NO_2, SO_2, CO and O_3 in Hangar 1 and in ambient air during 20-27.06.2014 (a) and 20-27.03.2015 (b)

Table 5

SPERMAN'S CORRELATION COEFFICENT FOR MUSEUM INDOOR (I) AND OUTDOOR (O) AIR QUALITY PARAMETERS, 20-27.06.2014

	I-NO2	I-SO2	I-CO	I-O3	I-PM 2.5	I-temp	I-RH	O-NO2	O-SO2	O-CO	O-O3	O-PM 2.5	O-temp	O-RH
I-NO2	1.000													
I-SO2	.094	1.000												
I-CO	**.635****	-.206**	1.000											
I-O3	-.318**	.452**	-.549**	1.000										
I-PM 2.5	.506**	.201*	.359**	-.322**	1.000									
I-temp	-.030	**.824****	-.342**	**.603****	.037	1.000								
I-RH	-.151	**-.626****	.020	-.092	-.341**	-.405**	1.000							
O-NO2	.498**	-.015	.445**	-.587**	.519**	-.163*	-.188*	1.000						
O-SO2	.041	**.782****	-.117	.380**	.147	**.817****	-.561**	-.048	1.000					
O-CO	.485**	-.046	**.619****	-.541**	.450**	-.228**	-.119	**.821****	-.065	1.000				
O-O3	-.355**	.413**	-.371**	**.733****	-.294**	**.649****	-.143	-.587**	.524**	-.525**	1.000			
O-PM 2.5	.128	.171*	.302**	-.096	-.100	-.085	-.535**	.131	.155*	.185*	-.107	1.000		
O-temp	.016	**.721****	.019	.380**	.067	**.730****	-.435**	-.156*	**.788****	-.064	.599**	.114	1.000	
O-RH	.054	-.564**	-.044	-.276**	-.028	-.439**	**.602****	.198*	-.660**	.101	-.494**	-.353**	**-.843****	1.000

Table 6

SPERMAN'S CORRELATION COEFFICENT FOR MUSEUM INDOOR (I) AND OUTDOOR (O) AIR QUALITY PARAMETERS, 20-27.03.2015;

	I-NO2	I-SO2	I-CO	I-O3	I-PM 2.5	I-temp	I-RH	O-NO2	O-SO2	O-CO	O-O3	O-PM 2.5	O-temp	O-RH
I-NO2	1.000													
I-SO2	-.021	1.000												
I-CO	**.674****	-.001	1.000											
I-O3	-.370**	.530**	-.425**	1.000										
I-PM 2.5	.065	.007	.290**	-.118	1.000									
I-temp	.226**	.253**	.284**	.154*	.280**	1.000								
I-RH	-.230**	-.143	-.244**	-.015	-.475**	**-.849****	1.000							
O-NO2	**.646****	.059	.480**	-.419**	.100	-.054	-.009	1.000						
O-SO2	.152	**.686****	.228**	.245**	.009	.235**	.010	.230**	1.000					
O-CO	**.659****	.125	**.650****	-.371**	.227**	-.029	-.035	**.880****	.289**	1.000				
O-O3	-.380**	.329**	-.353**	**.687****	-.185*	.183*	.042	**-.661****	.314**	-.561**	1.000			
O-PM 2.5	.118	-.266**	-.007	-.129	.455**	.338**	-.583**	-.108	-.438**	-.109	-.158*	1.000		
O-temp	-.143	.551**	-.174*	.544**	-.099	.208**	-.036	-.214**	.556**	-.143	**.651****	-.350**	1.000	
O-RH	.036	-.470**	.069	-.452**	-.124	-.087	-.062	.025	**-.637****	-.048	-.597**	.259**	**-.742****	1.000

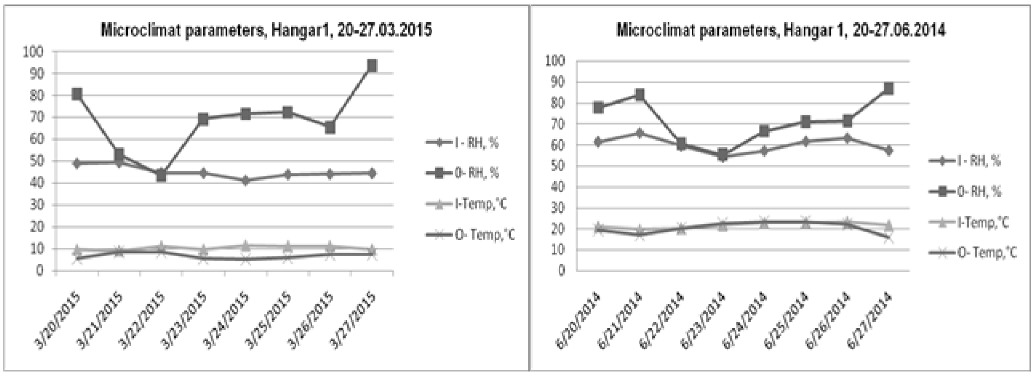
than in the warm season (11.26 $\mu g/m^3$), but below the lower intervention limit, 50 $\mu g/m^3$.

Also, analyzing the aspect of the curves we can observe that, for all pollutants, the concentrations inside the hangar are lower than outside, and the fluctuations of the outdoor concentrations are felt indoor, but the values are attenuated.

An indicator used routinely to evaluate indoor air quality in order to identify pollution sources is the I/O ratio, respectively the concentrations ratio inside and outside the building. Subunitary I/O ratio indicate a good insulation of the building, the absence of significant sources of indoor pollution and possible reactions of the compounds with exhibits or other chemical compounds present in the air [2]; supraunitary values or close to 1 may indicate the existence of an indoor pollution source or an intense exchange with the outdoor. Ratio values of I/O must be examined very carefully, taking into consideration the peculiarities of the building construction, insulation, and the efficiency of the ventilation especially when the values are close to 1.

In Hangar 1 it can be observed that, for all pollutants, I/O ratios are subunitary, with values in the range 0.32 to 0.8, which indicates the absence of major indoor sources of air pollution and a good isolation of the building. In the case of PM 2.5, concentrations are much lower indoor than outdoor (I/O = 0.44 during the hot season and 0.48 during the cold season) because of the reduced exchange with the outdoor, small number of staff who works in this space (2-3 people), fewer visitors, large volume of the room (approx. 1000 m^3) and frequent removal of dust from the floor and exhibits. Values obtained for I/O ratios also indicate that the main source of air pollution is the outdoor air.

Additional information on possible sources of pollution can be obtained by statistical correlation analysis between



(a) (b)

Fig. 3.Variation in time for temperature and RH in Hangar 1 and in the ambient air during 20-27.06.2014 (a) and during 20-27.03.2015 (b)

the data sets obtained indoor and outdoor. Given the results of verification tests for the normality of the distribution data (skewness and kurtosis) indicating deviations from the normal distribution, for the correlation analysis were used Spearman coefficients values, q (table 5 and 6). So, the good correlation between pollutant concentrations from inside and outside the building, with values of the Spearman correlation coefficient for NO_2 (q_{wam}= 0.498; q_{cold}=0.646), SO_2 (q_{warm}= 0.782; q_{cold}=0.686), CO (q_{warm}= 0.619; q_{cold}=0.650) and O_3 (q_{warm}= 0.733; q_{cold}=0.687) supports the hypothesis that the outdoor air is the most important source of air pollution inside Hangar 1.

Microclimate parameters variation

Referring the microclimate parameters it can be observed a reduced seasonal variation with short-term fluctuations (daytime) max 3.4^0C and 9.2% RH in hot season and max 5.2^0C and 7.7% RH in cold season, that meet the ASHRAE recommended range for conservation conditions, control class C - reduced risk for most items and books (in the range of 25-75% RH, temperature mostly <20^0C, rarely >30^0C). It can also be observed that the variations of temperature and humidity are lower indoor compared with outdoor (fig. 3) which demonstrates a good insulation of the building that attenuates the fluctuations creating appropriate conditions for preservation of the exhibits.

Spearman correlation analysis between data series measured inside and outside the building indicate good correlation in the hot season between outside and inside (Table 5) both for temperature (q_{temp}=0.730) and humidity (q_{RH}=0.602), but, in cold season, Spearman correlation coefficient values indicate weak and very weak correlations (q_{temp}=0.208; q_{RH}=-0.087) caused by the use of heat sources inside that influence the values of temperature and humidity indoor.

Conclusions

Based on the study of air quality assessment conducted in the showrooms belonging to the National Museum of Romanian Aviation we can conclude that the air quality in Hangar 1 is good, with the average concentration for the compounds monitored NO_2, SO_2, CO, O_3 and PM2.5 lower than the recommendations for preventive conservation of the exhibits. Also, the values of microclimate parameters are within a range that implies reduced risk for the type of exhibits displayed in the museum.

No presence of significant sources of pollution inside the building was identified, outdoor air representing the major source of pollution. Different indoor activities may cause sporadic emissions in the air and can provoke short increases of the concentrations without long-term effect.

In conclusion, we can appreciate that the indoor air from Hangar 1 and the microclimate conditions provided do not raise major issues for long term conservation of exhibits from the museum and do not require additional measures in terms of air quality and microclimate parameters.

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