INDOOR AIR QUALITY MEASUREMENTS IN MUSEUM MICROENVIRONMENTS

LAZARIDIS M.[1], COSTA C.N.[2], KATSIVELA E.[3], GLYTSOS T.[1*], KOPANAKIS I.[1], RAISI L.[3], THEOLOGIDES C.P.[2], PISKOPIANOU C.[2], CHATZIONA V.K.[2], CONSTANTINOU B.K.[2], VIOLAKI E.[4], GALENIANOU A.[4], KALOUTSAKIS A.[4] and KALOGERAKIS N.[1]

[1]School of Environmental Engineering, Technical University of Crete, Chania 73100, Greece, [2]Department of Environmental Science and Technology, Cyprus University of Technology, 30 Archbishop Kyprianou Str., 3036 Limassol, Cyprus, [3]Department of Environmental and Natural Resources Engineering, School of Applied Sciences, Technological Educational Institute of Crete, Romanou 3, Chania 73133, Greece, [4]Historical Museum of Crete, Sofokli Venizelou 27 / Lisimachou Kalokairinou 7, 71202, Heraklion, Greece
E-mail: thodoros.glytsos@enveng.tuc.gr

ABSTRACT

Indoor air quality in historical buildings and museums is receiving growing concern nowadays among the scientific community. Natural decay of many exhibited artworks is accelerated by non-controlled environmental conditions or by exposure to gaseous pollutants, airborne particles or microbes, emitted indoors or penetrating from the outdoor environment. Therefore, monitoring and controlling the indoor microclimatic conditions (temperature and relative humidity) and the levels of indoor pollution is of critical importance for the applied conservation and preservation strategies of cultural heritage. In this study, one year indoor/outdoor measurements of gaseous pollutants (NO_2, SO_2, O_3, VOC's, CO_2, acetic and formic acids) and microbial load were conducted at the Historical museum of Crete, located in Heraklion (Greece) and at the Limassol Municipal Gallery (Limassol, Cyprus). Passive diffusive samplers and on-line monitors were used for gas collection in both museums. Airborne microorganisms were collected with microbial air samplers. Furthermore, indoor and outdoor temperature and relative humidity were monitored throughout the measurement period. Data were collected at several locations inside the museums according to the vicinity of the exhibits, to possible outdoor air entries to the indoor environment (main entrance, open widows, etc.) In order to estimate the effect of indoor pollutants on vulnerable materials exhibited in the museums (wood, paper, leather etc), early warning dosimeters were deployed at several indoor locations and also outdoors. These dosimeters are sensitive to SO_2, NO_2, O_3, temperature, relative humidity, and UV-radiation and can detect unfavourable conditions before any noticeable changes on museum artwork are observed.

The results showed that the outdoor environment can significantly affect indoor air quality. In addition indoor activities and the presence of people can result in increased concentrations of indoor pollutants. The extent of the latter effect was not the same in all measurement locations, and depended on the combination of the presence of possible indoor pollution sources and the penetration of outdoor pollutants. The findings of this study can be used in the deployment of preventive actions regarding the protection of sensitive artworks from air pollution.

Keywords: Indoor air quality, Indoor/Outdoor measurements, airborne microorganisms, passive diffusive samplers

1. Introduction

Air pollution and its adverse effects on human health and the environment are of particular concern in the last decades. In addition air pollution is harmful to many materials. The direct effects of many contaminants in low concentrations are rather limited, but in the long term severe effects, such as surface deterioration, colour change and even weakening of the material may occur, especially for items composed of vulnerable materials like wood, paper leather, etc. It was assumed that works of art of great historical value are protected inside museums and archives, but this presumption was disproved by many studies showing the effects of indoor pollutants to sensitive materials. Indoor air quality is affected by emissions from indoor sources and by penetration of pollutants from the outdoor environment (Brimblecombe, 1990). Therefore it is important to focus on specific contaminants that are known to have deterioration effects on artworks.

Gaseous pollutants, mainly entering from outdoors can have a wide range of damaging effects on materials (Godoi *et al.,* 2013). More specifically, ozone is responsible for damaging a variety of oxidation sensitive materials and cause alterations and fading of pigments. NO_x and SO_2 are capable to damage photographic material and leather and cause the degradation of dyes. Exposure of certain objects to formic and acetic acids may result to corrosion of lead-containing alloys and other materials and reduction in the degree of polymerisation of cellulose in paper. Similar effects can be caused by volatile organic compounds, such as benzene, toluene and xylenes. Biodeterioration by microorganisms is a major threat for cultural heritage items (Schieweck *et al.,* 2005). Microorganisms can enter indoors through transport by the staff or visitors via their clothes or bodies of alternatively by natural ventilation through open gates and windows.

This work presents indoor and outdoor measurements of gaseous pollutants and indoor measurements of microbial concentrations at two sites (a museum and a gallery), located at costal/urban environments and influenced by vehicular traffic. The indoor microclimate was also monitored. The aim of the study was to examine the influence of the outdoor environment to the indoor pollutant's concentrations, determine the indoor microbial load and identify possible risk factors to sensitive works of art displayed inside the exhibition rooms.

2. Materials and methods

Indoor/Outdoor measurements were conducted at the Historical museum of Crete (HMC), located in Heraklion (Greece) and at the Limassol Municipal Gallery (LMG, Limassol, Cyprus) for one year (March 2014 to February 2015).

2.1. Heraklion Museum

The museum in Heraklion is located at the costal avenue of the city, approximately 500 m away from the city's center. The climate in Heraklion is characterized as Subtropical-Mediterranean, with warm to hot and dry summers and mild winters with moderate rain. The avenue in front of the museum is of high vehicular traffic throughout the year. The major pollution sources for the city of Heraklion are the power plants located about 13 km west of the city center. The museum is housed in a neoclassical building constructed in 1903. The building has expanded via a new wing in the 1970s, while a new floor was added in the new wing in 2004 (the building consists now of three floors). The Indoor exhibition space in the Museum currently stands at 1500 m^2, divided into 25 areas that cover seventeen centuries of history. The Museum also has a shop and a garden café. Air conditions systems are used for ventilation and for maintaining favourable conditions for indoor temperature and relative humidity. No natural light is allowed to enter inside the museum.

Three spots, one at each floor, were selected for the indoor measurements in the IMK. The spot on the ground floor (spot A) is very close the museum's main entrance and is housing representative items (maps, books, ceramics, etc.) of all the history periods covered by the museum's collections. The second spot (spot B), on the first floor was inside a painting exhibition, while the third spot (spot C) on the second floor was chosen in the area of the Ethnographic collection, where items of clay, stone, iron and wood are exhibited. Spot B was influenced by the outdoor environment via a door leading to the museum's cafe, which was open for long periods of time during summer and spring. Spot D was just outside the museum, on a balcony, about 2.5 m from the ground. Passive diffusive samplers for SO_2, NO_2 and O_3 were deployed in all measurement's spots (SO_2 was measured only during the cold period (October – March). A microbial air sampler was used to collect airborne microorganisms and sampling was performed once a month. The heterotrophic bacteria were grown in Tryptone Soy Agar, whereas the mesophilic fungi were cultivated in Malt Extract Agar. The autotrophic chemolithotrophic bacteria were grown in Minimum Mineral Tris Phosphate Agar without any carbon source, whereas acid producing bacteria were cultivated in *Gluconobacter* Indoor microclimate (temperature and relative humidity) was continuously monitored. Furthermore, early warning dosimeters were also placed in the measurement's spots. These dosimeters are sensitive to SO_2, NO_2, O_3, temperature, relative humidity, and UV-radiation and can through accelerating ageing techniques detect the effects on vulnerable materials. According to these effects, the indoor environment is characterized in a five stages scale in the range from poor to excellent.

2.2. Limassol Municipal Gallery

The Municipal Gallery of Limassol is located on the high-traffic coastal avenue of the city, approximately 1 km from the city centre. Limassol has very similar climatic conditions to Heraklion. The gallery building was constructed in 1938. The original building was expanded in 1996 with the addition of a new building which is attached to the original. Air conditioning systems (split-unit type) are used for indoor temperature and humidity control.

Five spots were selected for the indoor measurements in LMG and one spot for outdoor measurements (for comparison). Spot A is located close to the entrance of the building (ground floor of the old building), spots B, C and D at the at the ground floor, 1st floor and basement of the new building, respectively and spot E at the gallery's library. Spot A was highly influenced by the outdoor environment, since it was located at the entrance of the gallery. Spot F was located at the precinct of the building, approximately 5 m away from it. Passive diffusive samplers for acetic acid, formic acid, H_2S, NH_3, O_3 and NO_2 were deployed in all measurement spots. In addition, a portable gas analyser (Duvas Technologies) was used for the measurement of H_2S, NH_3, O_3, SO_2, NO_2 and BTEX at all measurement spots. A microbial air sampler was used to collect airborne microorganisms, while a particulate sampler was used for airborne particulates collection at all measurement spots. The air microbes were quantitatively evaluated, after the biological air samples were incubated at 37 ^oC (48h) and 20 ^oC (72h) for bacteria and fungi, respectively. Sampling was performed once a month. Furthermore, early warning dosimeters were also placed in the measurement's spots.

3. Results and discussion

3.1. Gaseous pollutant's concentrations

Gaseous pollutant's measurements results at LMG indicate a significant influence of the indoor air quality of the old building by the outdoor environment, which is expected since the latter measurement spot (spot A) is located close to the gallery's entrance. Relatively high concentrations were observed for O_3, H_2S and NO_2 at all measurement locations. The former two species seem to originate from the outdoor environment, since their concentration is very close to that observed at measurement spot F (gallery precinct). The highest indoor concentration for O_3 was measured at the old building (measurement spot A) which is the closest location to the gallery's entrance. On the contrary, the highest concentration of H_2S was observed at the basement of the new building. The latter result indicates an accumulation of H_2S at the lower lever of the building which is partly due to the large molecular weight (larger than the molecular weight of N_2 and O_2) and low diffusivity of H_2S. The presence of an indoor air pollution source (e.g., restrooms) cannot be excluded and may partially explain the latter phenomenon. It was surprisingly observed that a very high concentration of NO_2 was obtained at the old building of the gallery (measurement spot A). It is even more surprising that the average concentration of NO_2 observed at spot A is even higher than that measured outdoors (spot F). This indicates that there is an accumulation of NO_2 at the old building of the gallery a fact that deserves further examination. The actual reasons that lead to such an effect were not within the scope of the present work and will be examined in the near future within the framework of a separate study. Based on the above, the indoor environment of the gallery cannot be considered ideal, particularly for sensitive pigment artwork. In particular, the presence of relatively high concentrations of O_3 and H_2S significantly deteriorate the indoor air quality of the gallery. The old building of the gallery (spot A) presents the worst indoor air quality due to the presence of relatively high concentrations of O_3, H_2S but also NO_2 which is only present at high concentrations at measurement spot A. The latter part of the gallery is clearly inappropriate for housing sensitive artwork collections of high historical/cultural value.

Average indoor O_3 concentrations in the HMC ranged between 8.7±3.2 ppb and 9.1±5.8 ppb during the cold season (October to March) at the different indoor spots. The corresponsive values for the warm season (April to September) ranged between 7.5±0.3 ppb and 15.1±2.1 ppb, while the outdoor average concentrations were 27.3±3.4 ppb for the cold season and 34.4±1.4 ppb for the warm season. The effect of the outdoor environment was clearly visible in all occasions, since average concentrations presented spatial variations and their values increased according to the vicinity of the indoor spots to open doors and windows. On the other hand average NO_2 indoor concentration values showed lower differences to the outdoor concentration values both during the warm and the cold season (Indicative I/O ratios for site C were 0.69±0.08 for the warm season and 1.16±0.30 for the cold season). Furthermore, in the cold season the average indoor concentration was either equal or lower to the outdoor, indicating NO_2 accumulation in the indoor environment. This phenomenon was observed also in LMG and requires further investigation. The analysis of the results of the early warning dosimeters categorized the indoor environment between acceptable and very good (according to the spot and the month of the year) indicating that there is no imminent danger to the exhibits, but further actions could be made for the improvement of the indoor air quality.

3.2. Microbial load

In the present study, an attempt has been made to assess indoor microbial (bacteria and fungi) contamination levels at the Historical Museum of Crete and the Municipal Gallery of Limassol. Figure 1 shows measurements of air microbial contamination (fungi and bacteria), over a period exceeding one year, in six (6) selected spots at Municipal Gallery of Limassol. The data, which correspond to average values obtained from each set of samples, are given in the form of CFU/m^3.

As clearly seen in Fig. 1, bacterial contamination levels inside the gallery was found to be 120%, higher compared to outdoor measurements. This finding could be due to various factors, such as the presence of people, and insufficient ventilation inside the gallery. Additionally, bacterial air contamination was higher than the measured fungi growth in all the indoor samples tested (A-D), indicating that the gallery environment conditions appear to favour bacterial growth, while the fungal growth rates observed were significantly lower. Moreover it should be noted that the air bio-contamination didn’t show any seasonal fluctuation during the studied period, possibly due to the climate control systems (constant temperature and humidity) of the gallery, which appear to be efficient. In conclusion, almost all the selected spots of MGL were heavily contaminated with bacteria and fungi. Thus, attention must be given to control those environmental factors which favour the growth and multiplication of microbes in indoor environment, which cause a danger to sensitive museum artifacts.

On the other hand, a considerable variability was shown in the the concentrations of the airborne microbes measured in the indoor environment of HMC, which was mainly related to indoor activities (such as presence of visitors), and to the indoor microclimatic conditions (air exchange rate and relative humidity fluctuations). The indoor concentrations were up to 58 times higher than the corresponding outdoor concentrations, indicating microbial load enrichment in the indoor environment. Furthermore, an enrichment of acid producing airborne bacteria was detected as the Indoor/Outdoor ratio presented values between 13 and 58. In contrast, the airborne fungal concentrations were higher outdoors. The results established a clear correlation between the indoor bacterial concentrations and the number of visitors, and the air exchange in each measurement’s site.

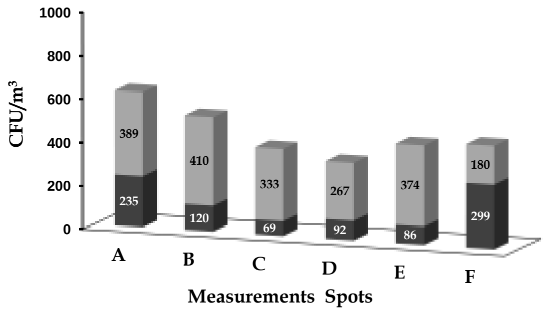

Figure 1: Air microbial (Bacteria and Fungi) contamination at the different measurements spots of the Municipal Gallery of Limassol.

4. Conclusions

Indoor/Outdoor measurements of gaseous pollutants and microbial concentrations were conducted at the Historical museum of Crete and at the Municipality Gallery of Limassol. The results showed that the indoor air quality in both sites is highly influenced by outdoor air quality. Outdoor air infiltration, through natural ventilation (doors, windows), appears to be the main factor leading to the deterioration of indoor air quality at the gallery, while it leads to increased gaseous concentrations in the HMC. The concentrations of O_3, H_2S and NO_2 at MGL were found to be higher than the recommended values reported in the literature for museum/gallery environments. The latter pollutants were found to originate from the outdoor environment. The high concentration of H_2S at the lower level (basement) of the gallery might partly be due to the presence of an indoor air pollution source. NO_2 was found to accumulate at the old (original) building of the gallery. O_3 concentrations in HMC were spot dependant and presented higher values to spots close to open doors and windows. Indoor NO_2 concentrations were very close to the corresponsive outdoor concentrations during the cold season and in some cases their values exceed the outdoor ones.

Bacterial contamination levels of the indoor air for both sites were found to be significantly higher compared to outdoor measurements, while the opposite is true for fungal contamination. Air bio-contamination inside the gallery didn't show any seasonal fluctuation during the studied period at LMG, possibly due to the climate control systems of the gallery, which appear to be efficient. On the other hand seasonal variability of the microbial concentrations was observed in HMC and furthermore the microbial load was correlated to the number of visitors and the air exchange rate at each spot. Conclusively it is reported that immediate actions must be applied in the LMG for the improvement of indoor air quality, while although there is no imminent danger for the exhibited artworks in HMC, mitigations measures could lead to improved indoor conditions in the museum.

ACKNOWLEDGEMENTS

This work was performed under the Operational Cross-Border Cooperation Programme «Greece-Cyprus 2007-2013» and was co-financed by the European Union (ERDF) (80%) and national funds of Greece and Cyprus (20%).

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