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SCREENING INDOOR AIR QUALITY EVALUATION IN THE LITHUANIAN THEATRE, MUSIC AND CINEMA MUSEUM

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Abstract. Air pollution is a risk for human health and for the preservation of materials in particular cultural heritage objects. This paper presents the main results obtained in the project carried out by the Lithuanian Theatre, Music and Cinema Museum (LTMCM) and NILU-Norwegian Institute for Air Research. The main goal of the project was to perform a screening study and characterization of the indoor air pollution in the LTMCM. The results are used to assess the indoor air quality with regard to the preservation of cultural heritage objects therein. Measurement of NO_2, organic acids (i.e. acetic and formic acids), photo-oxidant effects of the environment, climate (temperature and relative humidity) and particulate matter deposition were performed in different indoor locations. Low concentration of outdoor generated pollutants such as NO_2 was found in storage rooms whereas higher concentrations were determined in the in the exhibition area. The results indicate that the building envelope does not protect effectively against infiltration of outdoor pollutants such as NO_2 and particles. Very high concentration of indoor generated pollutants such as acetic acid was found in one storage room with a significant source.

Keywords: Air pollution, Indoor air quality, dosimetry, NO_2, acetic acid, preservation, pollutant infiltration.

Introduction

Air pollution and its effects on cultural heritage (CH) objects have received an increased interest in the last decades. Air pollution constitutes a risk to materials and in particular to cultural heritage objects and artworks (Brimblecombe 1990; Kunera, Fitz 1995; Tétreault 2003; Hatchfield 2002). Some of the documented adverse effects include the fading of paintings, blackening of surfaces, corrosion of metals, softening of details, decomposition and yellowing of paper, among other problems (Tétreault 2003).

According to their sources, indoor air pollutants can be divided into two main groups, those generated outdoors and subsequently infiltrated indoors, and those generated indoors. Nitrogen dioxide (NO_2), ozone (O_3), sulphur dioxide (SO_2) and particulate matter (PM) are among the most common outdoor pollutants which enter the museum environment. Ozone is also indoor generated as for instance from automatic photocopying (Valuntaitė, Girgždienė 2008), however this activity is not common in museum environments. The pollutants emitted indoors are mainly organic (e.g. volatile organic compounds, VOCs) and usually emitted from building materials (Schieweck *et al.* 2005). Several studies have been published about air pollution in museums (Brimblecombe 1990) and the degradation effects on CH objects (e.g. Thomson 1986; Blades *et al.* 2000; Hatchfield 2002; Tétreault 2003). For instance, ozone and NO_2 are strong oxidants which effects on cultural heritage materials are well known. Some of the most documented effects are corrosion of metals (Eriksson *et al.* 1993; Leygraf, Graedel 2000), attack on calcareous stones and murals (Johansson *et al.* 1988), fading and colour change of pigments (Kadokura *et al.* 1988; Salmon, Cass 1993; Whitmore, Cass 1988; Lynn *et al.* 2000), embrittlement of photographic and paper based materials (Reilly *et al.* 2001; Blades *et al.* 2000) and/or soiling.

Additionally, organic compounds have adverse effects on materials, such as the formation of salt efflorescence on carbonate materials (Gibson *et al.* 1997), embrittlement, fading and degradation of pigments (Oikawa *et al.* 2006), depolymerisation of cellulose material (Dupont, Tetreault 2000) and the corrosion of metal (Tennent *et al.* 1993).

The valuable objects in the Lithuanian Theatre, Music and Cinema Museum constitute a wide representation of the modern Lithuanian history. However, degradation is observed on several objects both in exhibition and storage, which indicates that their preservation may be at risk. Degradation mechanisms can be symptomatic of an unacceptable indoor environment with regard to climate parameters, such as temperature and relative humidity, or pollutant concentration.

The main goal of the project was to perform a characterization of the indoor air pollution in the LTMCM. In order to achieve this goal, a screening study was performed based on measurements carried out both in the storage and exhibition areas. Dosimetry (EWO dosimeter;

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Grøntoft *et al.* 2010), single pollutant concentrations (i.e. NO_2 and organic acids) determined by passive diffusion gas samplers and the evaluation of particle deposition on glass slides were the methods selected for the study.

1. Methods

1.1. Sampling location

The museum is located in the Radvilai Palace in the heart of Vilnius Old Town. The historic palace housed the Public Theatre of Vilnius between 1795 and 1810, and during the second part of 19th century, it was used as houserooms, shops and a pharmacy. The dimension of the museum is around 3718 m^2, of which more than 1500 m^2 are dedicated to exhibition area and approximately 500 m^2 to depository or storeroom.

The museum collection consists of a wide range of valuable Lithuanian CH objects, reaching over 350 thousand exhibits which are placed mainly in the storage rooms and, a small part of them, in exhibition. The main group of objects can be classified as paper based materials, for instance programme sheets, posters, newsletters, photographs, and manuscripts among others. Other representative groups are composed mainly by wooden objects, such as rare music instruments from 18^{th} – 20^{th} century, and metal objects. The collection includes in addition films, vinyl, paintings, sound recording and textiles, such as costumes from personal collections of renowned Lithuanian actors and actresses.

The museum is a naturally ventilated building located in the city centre of Vilnius. One of its two main facades faces a street with intense traffic whereas the other is facing a backyard (Fig. 1). Five different sampling locations were selected inside the building in order to cover different environmental conditions. Two of the sampling locations were in storage rooms (LM1 and LM2; Table 1 and Fig. 1) whereas the remaining three sampling locations were in exhibition areas (LM3, LM4 and LM5; Table 1 and Fig. 1). In addition, different physical characteristics such as presence or absence of window (Table 1) and whether the room is facing street or backyard were taken into account as criteria for the selection of the sampling location.

1.2. Climate

Punctual measurements of temperature and relative humidity were carried out on a daily basis in the five sampling locations by the personnel of the museum from February to May 2010. Both temperature and relative humidity were measured with miniature thermo-hygrometers TFA with ± 1 ºC and ± 5% RH accuracy.

1.3. Dosimetry

The photo-oxidant effects of the environment were measured by the Early Warning dosimeter for Organic materials (EWO) developed by NILU-Norwegian Institute for Air Research (Grøntoft *et al.* 2010).

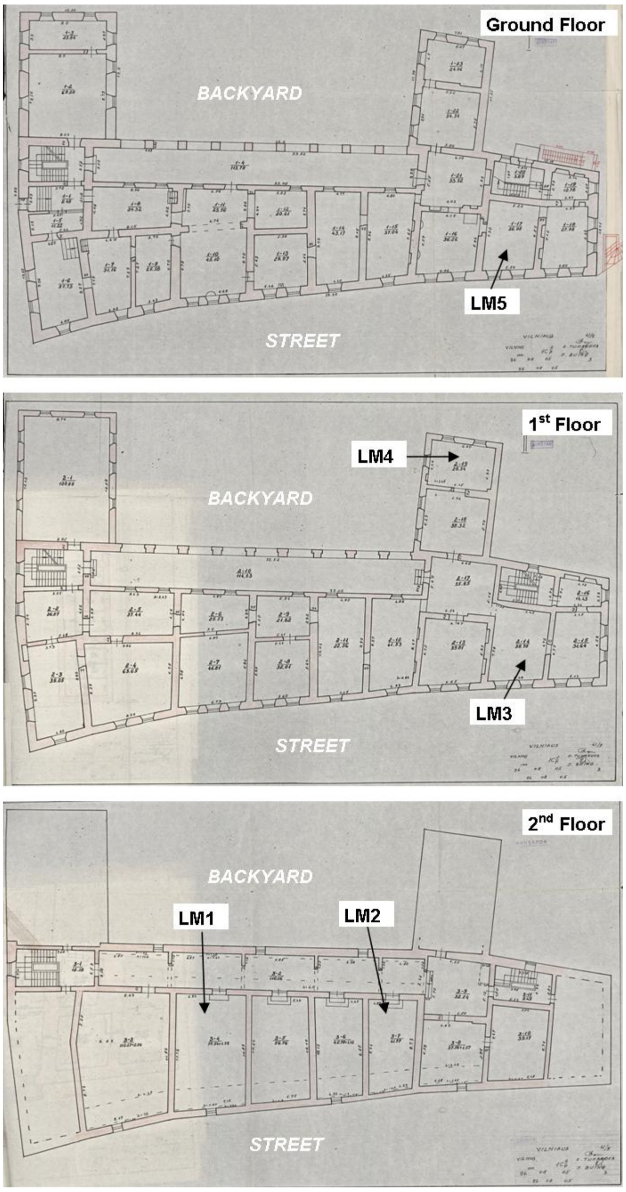

Fig. 1. Distribution of sampling locations in the Lithuanian Theatre, Music and Cinema Museum

Table 1. Description of sampling locations

Ref	Floor	Room type	Material type	Description
LM1	2nd	D	Various - mainlypaper	Scenography depository, with window to the street
LM2	2nd	D	Various - mainlywood	General depository, without window.
LM3	1st	E	MainlyWood and metal pieces	Room faces the street side
LM4	1st	E	Paper and Paintings on the wall	Room faces the backyard
LM5	Ground	E	Textile, metal, paper	Room faces the street side at street level

The EWO dosimeter is a synthetic polymer sensitive to climate parameters (i.e. temperature, relative humidity and UV Light) and NO_2 and O_3, which are usually emitted outdoors and ventilated or infiltrated into the indoor environment. The environmental effect on the dosimeter polymer film is measured by photo-spectrometry as the change in UV absorption at 340 nm from before to after three months exposure. The relation between the EWO-response and the environment is based on a non linear dose response function found from the statistical analysis of the results obtained in a measurement campaign. Dose response functions for indoor locations have been defined (Grøntoft *et al.* 2010). The evaluation of recommended response levels for the EWO dosimeter as compared to effects on organic CH objects is performed based on existing knowledge in conservation science about the effects of the single environmental parameters on the heritage objects. The results from the measurements carried out with the EWO dosimeter are reported as values of increasing environmental impact ranging from one to five, which correspond to different locations with different degree of protection, from archive (i.e. Level 1) to external storage with no control (i.e. Level 5).

1.4. Passive diffusion samplers

Organic acids (i.e. acetic and formic acid) and NO_2 concentrations were measured by passive diffusion gas samplers (Ferm 1991) from the Norwegian Institute for Air Research. Two parallel passive samplers for each compound were exposure during one month in the five sampling locations, thereafter the samplers were sent to the laboratory for analysis.

The filter of the organic acids passive diffusion sampler is impregnated in an alkali, which is dissolved in an aqueous solution after exposure and the extracted acetate and formate are determined by ion chromatography. The mean concentration during the exposure time is estimated based on the quantity of extracted acetate and formate, a constant, which contains the diffusion constant for acetic and formic acids, and a factor based on the dimensions of the passive diffusion sampler. The filter of the NO_2-passive sampler is impregnated in iodide (I-) and the formed nitrite (NO_2^-) is determined by photometry. The NO_2 average concentration for the exposure time is estimated in the same way as for organic acids. The detection limit for NO_2 after one month of exposure time is approximately 0.03 $\mu g\ m^{-3}$ and for acetic acid and formic acid it is 0.5 $\mu g\ m^{-3}$.

1.5. Particle deposition

Glass slides were exposed during three months in the sampling locations selected in the LTMCM. After exposure the glass slides were covered with GelLifter© and the deposited particles were collected and examined by microscopy. The GelLifters© were analyzed by optical microscopy using a Leitz Aristoplan microscope. Digital images where taken using a Leica DC Camera attached to the microscope and assisted by Leica IM Management system. The digital images are analyzed by the image processing software ImageJ.

2. Results and discussion

2.1. Climate

Relative humidity represents an essential environmental factor for the diagnosis and risk assessment for CH objects. Several materials (e.g. wood, paper, parchment, leather, bone, paintings, plaster or clay mineral based stones) are very sensitive to their water content, which is in equilibrium with the relative humidity in the air. Changes in the moisture content influence changes of the physical state of the materials. For instance, when moisture is removed from some materials such as wood or bone they contract favouring distortion or cracking. Other materials such as paper, parchment, leather and natural textiles become less flexible and therefore more fragile.

Temperature and relative humidity in the LTMCM are summarized in the Table 2. The temperature is found to be low in every location and does not show significant variations, whereas relative humidity shows some variations, higher in the exhibition gallery than in storage areas. Deformation of wooden instruments such as changes in volume or cracking has been observed in the LTMCM, and in particular in the instruments exhibit in the gallery. The relative humidity variations observed during four months (i.e. February 2010 to May 2010) may explain these effects. However, seasonal variations are expected to have stronger impact.

Table 2. Average temperature and relative humidity (4 months), Max and Min. Numbers in brackets are standard deviations

#	T (°C)			
	Aver		**Max**	**Min**
LM1	13.9	(1.9)	18	10
LM2	13.9	(1.7)	17	12
LM3	14.3	(1.7)	18	12
LM4	13.0	(1.5)	16	9
LM5	13.8	(1.8)	19	10
#	**RH (%)**			
	Aver		**Max**	**Min**
LM1	46.0	(4.7)	53	39
LM2	35.9	(5.3)	45	28
LM3	35.2	(12.6)	54	21
LM4	41.2	(12.7)	62	29
LM5	40.4	(9.2)	63	27

The LTMCM hold a significant collection of paper based material and climatic parameters may be concerns for the preservation of this type of materials. According to the preservation index (PI) developed by the Image Permanence Institute (IPI 2000) for paper based and photographic material, the average temperature and relative humidity obtained in the five indoor locations involve 1) slow natural aging rate (i.e. PI = 124 years); 2) there is no risk for mold germination; and 3) the conditions are recommended for the storage of photographic material. However, high values of relative humidity measured in some of the locations (i.e. 63% RH) involves lower preservation index for paper based materials (i.e. PI = 65 years). In addition, the highest relative humidity value measured in the museum involves moderate natural aging rate and conditions not recommendable for the preservation of photographic material. For paper based material and photographic materials, relative humidity above 50% is not recommendable due to fast increase of the natural aging rate.

2.2. Environmental photo-oxidant effects

Figure 2 shows the results obtained with the EWO dosimeter. Three out of five locations are classified as level 1, which means that the environment, concerning photo-oxidant effects on organic materials, is acceptable for an "Archive Store". LM1 and LM2 are storerooms, so the results are in conformity with the type of indoor location and therefore the environment is acceptable. In addition, the response of the EWO dosimeter in LM2 is cero. This room is a depository room without windows and therefore low infiltration of outdoor generated pollutants, such as NO_2 and O_3, and low levels of light. The location LM3 is part of the exhibition gallery and faces the street side of the historic building (Fig. 1). Therefore the level 1 obtained by the EWO dosimeter (Fig. 2) indicates that the gallery room LM3 has an excellent environment concerning photo-oxidant effects.

The remaining two sampling locations (i.e. LM4 and LM5) showed acceptable environment for a "Purposed Built Museum" (Level 2; Figure 2) very close to acceptable for a "Historic House" (i.e. Level 3). Both locations are used as exhibition area; one of them faces the backyard (LM4) whereas the other faces the street (LM5; Fig. 1). These locations are gallery rooms of the historic building so level 2 obtained with the EWO dosimeter indicate that the environment is very good.

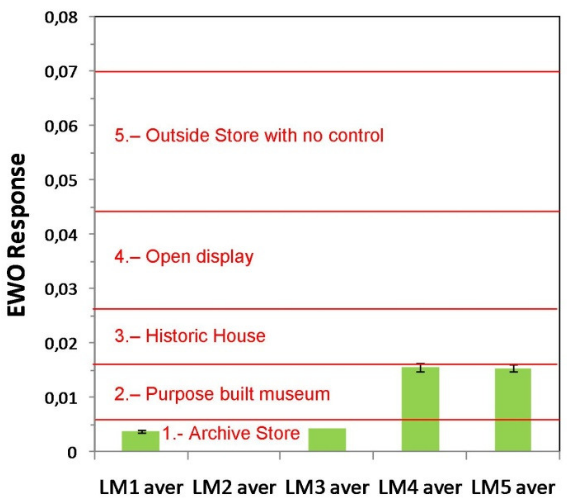

Fig. 2. EWO dosimeter responses (ΔLight absorbance) obtained in the five indoor locations in the LTMCM

2.3. Outdoor pollutant – NO_2

In the absence of indoor sources, NO_2 is an outdoor generated pollutant which infiltrates into the indoor environment. The concentration of NO_2 in the LTMCM varies from 1 μg m^{-3} to approximately 30 μg m^{-3} (Fig. 3). The lowest concentrations were measured in the depository or storerooms (LM1 and LM2; Fig. 3) located on the top floor of the museum. The measurements performed in the exhibition areas show values above 10 μg m^{-3}, and the highest level is obtained in the room located at the ground floor and facing the street side of the building (LM5; Fig. 3).

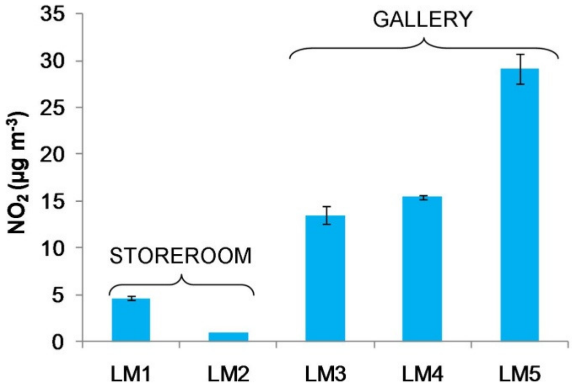

Fig. 3. NO_2 concentration obtained in the LTMCM. Values represent the average from two parallel samplers. For abbreviation and locations characteristics see Table 1

In order to evaluate the infiltration of outdoor pollutants into the museum, different locations were selected from the building. The locations LM3 and LM4 were selected from the same floor; LM3 faces the street, whereas LM4 faces the backyard. The results obtained do not show differences between both rooms (Fig. 3) and therefore the location within the building concerning the distance to traffic emissions is not a determinant parameter. The worst case scenario is observed in the room location LM5, where the concentration of NO_2 reaches 30 μg m^{-3} (Fig. 3). The location LM5 is at the ground floor at approximately 2 meters from the traffic.

Outdoor NO_2 concentration in Vilnius during the NO_2 sampling period (February 2010) was available (Know your air for health 2010). Hourly NO_2 concentration data from three different monitoring stations distributed across Vilnius was collected and analysed. Average daily NO_2 concentration varies between 7 and 38 μg m^{-3} in the background (i.e. Lazdynai) and industrial stations (i.e. Sabanoriu), whereas daily average NO_2 concentration is between 17 and 62 μg m^{-3} in the traffic monitoring station (i.e. Zirmunai; Fig. 4).

The traffic station was selected as representing of the outdoor air quality around the LTMCM (Fig. 4). The month average concentration of NO_2 for the exposure time of interest is 39.27 μg m^{-3} (standard deviation: 10.67). Taking this value into account, we obtain an indoor / outdoor ratio (I/O) between 0.02 and 0.74 (Table 3). The lowest I/O ratio is observed in the two storage rooms, LM1 and LM2, indicating very low infiltration of NO_2, whereas the highest I/O ratio is obtained in the location LM5 illustrating that the building, and specifically the room LM5, does not protect efficiently against infiltration of outdoor pollutants.

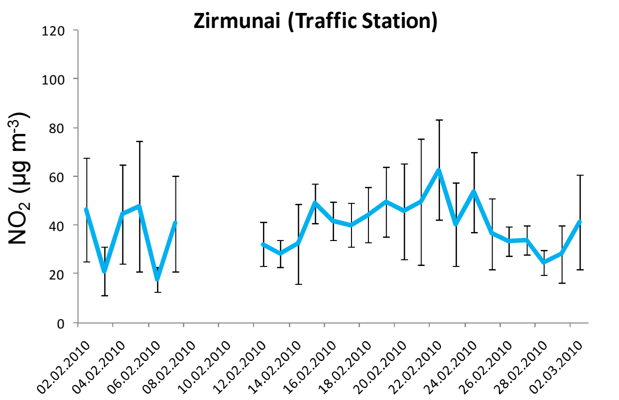

Fig. 4. Daily average outdoor NO_2 in Zirmunai monitoring station. The bars represent standard deviations

Table 3. I/O ratio obtained in the different locations

LOCATION	I/O
LM1	0.12
LM2	0.02
LM	0.34
LM4	0.39
LM5	0.74

The recommended NO_2 concentration in the museum environment for the preservation of most objects is 10 µg m^{-3} (Thomson 1986; ASHRAE 2003) and the US National Bureau of Standard (NBS 1983) suggests 4.75 µg m^{-3} of NO_2 as recommended limit value for exposure of paper based materials. The concentrations of NO_2 in the exhibition areas are found to be above 10 µg m^{-3}, indicating that the CH objects in the gallery may be under risk.

2.4. Indoor pollutant – organic acids

Organic acids were selected as indicator of indoor generated pollutants as they are mainly emitted from materials such as wood, paint and varnishes (Hatchfield 2002; Tétreault 2003). The concentration of acetic acid measured inside the LTMCM varies from 19 µg m^{-3} to approximately 280 µg m^{-3} (Fig. 5). The lowest acetic acid concentration is measured in the location which faces the street at ground level (i.e. LM5; Fig. 5), whereas the highest concentration of acetic acid is measured in one of the storeroom (i.e. LM1; Fig. 5). Formic acid follows the same pattern as acetic acid (Fig. 5). LM1 is a depository room with a large number of wooden drawers from which high emission of organic compounds may occur. The low concentration of organic acids determined in LM5 may be explained by the building materials as it has stone floor, while the others have wooden floors. Additionally, high infiltration is found to be in LM5 based on the I/O ratio of NO_2 (Table 3), which may involve high dilution of indoor generated pollutants.

Concerning the preservation of CH objects, the location LM1 is the main concern due to the high concentration of organic acids (i.e. ≈280 µg m^{-3} of acetic acid; ≈40 µg m^{-3} of formic acid). Acetic acid is known to corrode metals, in particular lead (Tennent *et al.* 1993), it degrades calcareous materials (Tennent *et al.* 1992) and reduces the degree of polymerization of cellulose in paper (Dupond, Tétreault 2000). LM1 mainly holds paper based materials which may be under risk. According to the ISO 11799 (2003) concerning the requirements for archive and library material, the recommended levels of acetic acids are below 10 µg m^{-3}. However, this value is very low as normal indoor concentrations levels commonly vary between 40 – 100 µg m^{-3} (Tétreault 2003).

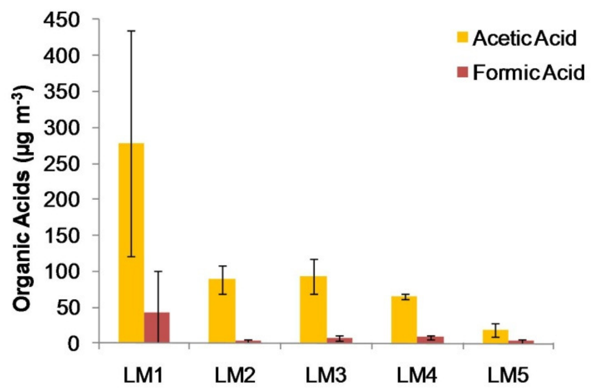

Fig. 5. Organic acids (acetic and formic acids) concentration measured in the LTMCM. Values represent the average from two parallel samplers. For abbreviations and location characteristics see Table 1

2.5. Particle deposition

Fig. 6 shows the results obtained from the study of glass slides exposed over three months in the five sampling locations. The results represent average percentage of area covered with particles obtained over a study area of approximately 8 mm^2. The highest value was obtained in the location LM5, followed by LM1, whereas the lowest value was obtained in the location LM2.

The particles deposited on the glass slides are mainly equidimensional and a low percentage of fibres were observed. In general, particles are transported into the museum by visitors or are infiltrated through the shield of the building (Nazaroff *et al.* 1993). The high value obtained in the location LM5 might correspond to infiltration from outdoor environment. The sampling station was placed on the interior windowsill at approximately 3 meters from the visitor path. The lowest obtained value (LM2; Fig. 6) is in accordance with the characteristics of the room; restricted personnel access and lack of window.

The highest percentages of area covered with particles were obtained in the three locations with windows facing the street (LM1, LM3 and LM5; Fig. 6). In addition the morphology of the particles is mainly equidimensional and low percentage of fibres brought by visitors was observed. These results indicate that particles are most probably infiltrated into the building through windows and doors. Thus the building does not protect effectively against the infiltration of particles. Particles constitute a risk for cultural heritage objects in museums as they cause soiling, are abrasive, provide sites for surface reactions and have a potential to damage artefacts due to their hygroscopic nature (Nazaroff, Cass 1991).

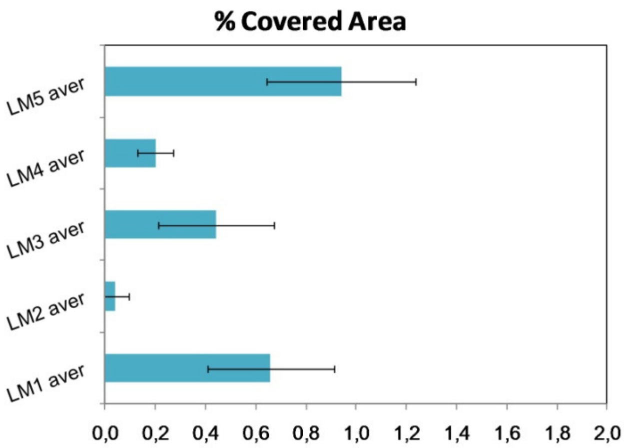

Fig. 6. Average percentage of area covered with particles obtained in the five indoor locations in the LTMCM. For abbreviations see Table 1

Conclusions

The screening study performed inside the Lithuanian Theatre Music and Cinema museum give a good indication of the indoor air quality concerning the preservation of CH objects. However, additional research is needed in order to perform a more complete evaluation concerning material exposure or even human exposure. The measurements carried out in our study have been performed only during one (single gas concentration) and three month exposure time (dosimetry). Additional information about seasonal variations of pollutant concentrations, air exchange rate of the building, particulate matter concentration and compositions, the concentration of other pollutants such as aldehydes or ozone would be of large interest.

Nevertheless, the measurements performed in our screening study allow us to establish certain conclusions and basis for further studies. The indoor air quality in the studied storage rooms of the LTMCM is "acceptable" concerning the photo-oxidant effects of the environment (i.e. synergistic effects of temperature, relative humidity, UV light, NO_2 and O_3) on organic materials. In addition, the studied exhibition rooms of the LTMCM show "very good" and "excellent" environments. However, there is reason of concern based on the results obtained from single pollutant concentration measurements. Outdoor generated pollutants such as NO_2 is a main concern in the exhibition areas of the museum as the determined concentrations are above recommended values for the preservation of most objects (i.e. 10 µg m^{-3}). In addition, the results obtained by the study of particle deposition may indicate high infiltration of course particles in rooms with windows facing the streets. Indoor generated pollutants such as acetic acids are a main concern for sensitive materials placed in storage rooms with a significant pollutant source.

The results obtained in the gallery of the LTMCM indicate that the building does not protect effectively against the infiltration of outdoor pollutants such as NO_2 and particles which are a risk for the preservation of cultural heritage objects in exhibition. This study contributes to the understanding of pollutant infiltration in naturally ventilated historic buildings and it constitutes essential basis for more detail characterization and evaluation of the indoor air quality in the museum environment.

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