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MONITORING OF POLLUTANTS IN MUSEUM ENVIRONMENT

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Abstract. Art works are affected by environmental factors as light, temperature, humidity. Air pollutants are also implicated in their degradation. The pollution in museums has two sources: the air from outside, which brings usually dust and inorganic particles, and the inside sources – the materials used for casings (sealants, textiles placed on the display cases, varnishes, wood) that emanate organic compounds. The dust is composed of particles with a diameter of approximately 2μm or higher, which come from soil (silica) or animal and vegetal residues (skin cells, pollen). They facilitate water condensation on objects surface and biologic attack. The inorganic compounds are a result of materials combustion (SO_2, NO_2, NO) and in presence of water they form acidic compounds which affect the museum objects. The organic compounds are usually peroxides, acids, phthalates, formaldehyde. The effects of these pollutants are: soiling, surface discolouration, embrittlement, corrosion. Therefore, conservators are interested in monitoring the pollution degree in the display cases or in the museum air and in analyzing the effects of pollutants on the exhibited objects. They use different methods for pollutants identification, like direct reading devices based on colorimetry, that can be read after few minutes and hours (they interact with the pollutants in atmosphere), or indirect reading samples that require a laboratory. The information gathered is used for the identification of pollution source and to analyze the concentration of pollutants needed to provoke damages on the surfaces of art objects. This paper is a review of pollutants that affect the art objects and of the monitoring systems used for their identification and measuring.

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Introduction

The museums have objects made of different materials (metals, textiles, wood etc.) which degrade in time under the influence of various factors like light, humidity, temperature, biological factors, and pollutants. The pollutants can be dust particles and gases brought from outside through the ventilation system or by visitors, alkaline particles from building renovation, volatile compounds released by the materials used in restoration or in making of display cases. Because of the various materials used for casings and display the indoor pollutants can have higher concentrations than the particles and gases brought from exterior [Thickett, 2004].

The dust is carried inside the museum by natural ventilation or by visitors' shoes or clothes. It is made of particles of organic and inorganic origins like soil, soot, textile fibers, vegetal or insect fragments, skin cells, hair. Some of them have large dimensions (soil particles go from 1-300 μm) [Yoon, 2000; Lloyd, 2011] and land on objects due to force of gravity, others are smaller and interact with the objects through Brownian movement or electrostatic forces [Nazaroff, 1993]. The soot is a result of fuel burning and forms black deposits on the objects. The presence of dust brings the following disadvantages: it helps water vapours condensate on the object's surface [Moldoveanu, 2010]; its particles adsorb gaseous pollutants like SO_2 from the atmosphere and facilitate the object's contact with more aggressive substances [Thickett, 2004], the organic particles are a source of food for microorganisms which produce exopolymers that embed other dust particles and change the aspect of the art objects [Tarnowski et al., 2004]; the abrasive particles can lead to little scratches on the objects' surface when removed.

Gases like SO_2, NO_x, nitric and sulphuric acid are brought from outside and affect the museum objects by reacting with the component materials. Some of the degradations that occur are: decomposition of limestone, disolouring and rigidity of leather, brittleness of textiles, efflorescence of fossils, metal corrosion.

There are also alkaline particles that are released by the new concrete and affect the protein materials by decreasing their tensile strength [Slade, 2003].

The volatile organic compounds (VOC) can be emitted by materials used for the conservation of objects, for example the solvent used for dammar varnish releases aliphatic and aromatic compounds [Schieweck, 2008]. Also, the materials used for the display cases present a risk for pollution. The dyes used to colour the textiles, the cloths made of wool, rubber emanate sulphur compounds which interact with organic objects like bones. The wood components degrade under the influence of light, humidity, oxygen or high temperatures creating volatile compounds like aldehydes (formaldehyde), and organic acids (acetic acid, formic acid). The quantity of VOC emitted depends on the type of wood, the period of its harvest, the drying method (air dried wood release a smaller quantity of VOC) [Thickett, 2004]. The adhesives used in the MDF fabrication, urea-formaldehyde, phenol-formaldehyde or melamine-formaldehyde, can release formaldehyde if the polymer isn't cured or the polymerization was incomplete [Schieweck, 2008]. Other materials that emit VOC are the lakes, paints, sealants (polyurethane foams). These VOC can be absorbed by other materials from the cases and released slowly in time, continuing their action on the displayed objects, even though the source of pollution was removed [Tétreault, 1994].

For the monitoring of these pollutants there are different devices which can show the type of substances that are affecting the collections, their concentration and their disposition in the museums rooms.

Monitoring tools

The dust that is brought inside the museum by ventilation or visitors can be sampled with the help of adhesive strips (labels made of vinyl or Teflon, or even usual labels), placed near the objects or at ground level. The strips are positioned vertically or horizontally and left for a certain period of time (days or weeks) [Lloyd, 2011]. The small particles can be analyzed with the help of optical microscopy, SEM or ion chromatography and the results are used to identify the source of pollution [Smolík, 2013]. A correlation can be made between the type of weather, the number of visitors, the place of the strips and the particles concentration [Yoon, 2000]. For dust collection there can also be used cellulose filters placed horizontally [Smolík, 2013].

More sophisticated devices created for measuring the size and concentration of particles in the air are the optical instruments like nephelometers, based on light scattering, or aethalometers, which use light absorption. The nephelometers have a small chamber illuminated by laser, in which air with particles is drawn. These particles reflect the light, which is captured and transformed into electric pulses by a photodetector. The pulses are analyzed by a computer that converts the information into data about particles. Depending on the reflectivity of the particles, the device may consider them larger or smaller than they really are. Because of the size of the chamber, a single measurement is not enough; therefore, to obtain a realistic analysis of the air, several samplings are required, in different points of the room [Westby, 2011]. Aethalometers are used to determine the concentration of the black carbon particles, resulted after fuel combustion. The particles from the sampled air are retained on a quartz fiber filter and absorb a part of the light emitted by a LED lamp. The rest of the light passes the filter and reaches a diode placed under it. The amount of light received by the diode is inversely proportional to the particle concentration. The data are converted and analyzed by a computer [Hansen, 2000].

To identify the gases and VOC and to determine their concentrations, different devices based on active or passive sampling can be used. The active sampling uses the absorption of polluted air into a tube, with the help of a pump. The gases cumulate in a sorbent material (charcoal) and they are thermally desorbed into a gas –chromatograph, where they are analyzed [Hatchfield, 2004]. Other type of active sampling uses tubes with a colour changing sorbent and a scale. The concentration of the gases is indicated by the level of the colour changed sorbent [Druzik, 1991].

The passive sampling method comprises devices (badges, diffusion tubes, dosimeters) that absorb freely the pollutants. They have a diffusion medium for gases – air or gels. The identification of gases or the concentration of the pollutants can be realized immediately because the gases change the colours of samples, or they require laboratory analysis, usually made at the company that provides the instruments.

Badges are small passive sampling devices. There are two types: with a sensitive surface that changes its colour in the presence of a specific gas or with synthetic carbon/charcoal encapsulated in Teflon, with a diffusion space of 1 cm height. The badges are usually created for the working personal, therefore they require circulating air. They detect pollutants in concentration of ppm or ppb. They can be analyzed directly, by comparison with references provided by the manufacturer, or in a laboratory [Hatchfield, 2004; Grzywacz, 2006].

The diffusion tubes are used for identification of gases like SO_2, NO_2, H_2S, O_3, carbonyl sulfide or VOC, and are based on gases diffusion from high to low concentrations [Hatchfield, 2004]. There are tubes made of glass that contain a specific material that reacts with a specific pollutant (e.g. pH indicators for SO_2 and acetic acid), resulting a colour changing correlated with the time of exposure (hours) and concentration [Grzywacz, 2006]. Other tubes are made of acrylic or polypropylene, with a cap at each end. At the beginning the tubes are closed at both ends, but when are used for sampling they are opened at the lower end and positioned vertically in an area with circulating air, for 2 -4 weeks. In the upper cap there is a sorbent material, like triethanolamine for NO_2. They measure concentration of ppm, but they are less accurate than electric devices [Targa 2008; Nash, 2010; http://www.ormantineusa.com/]. The tubes are analyzed in a laboratory. There are also diffusion tubes that contain an absorbent (charcoal) that will impregnate with pollutants. This type of diffusion tubes require, too, a longer time for exposure (weeks) and can detect smaller amounts of pollutants (ppb). The analysis of the pollutants is made at the producer company, by heating the absorbent material and transferring it to a GC-MS or by spectrophotometry [http://www.ormantineusa.com/].

The dosimeters are made of polymeric films, metals, textiles. The polymeric films change their spectra after interacting with pollutants and this fact can be used to determine the pollutants and their concentration [Slade, 2003]. The metal dosimeters made of copper, silver and lead corrode when in contact with pollutants like chlorides, sulphides, acids and the corrosion products can be identified using FT-IR, for example. The dosimeters can also be weighed, so the concentration of pollutants can be evaluated [Grzywacz, 2006].

Metal samples made of lead, copper and silver are also used in Oddy tests which verify the safety of the materials used in display cases. The material tested is put in a glass recipient, where is also a test tube filled with distilled water and closed with a cotton ball. The metal sample is bound with a thread which is caught in the recipient lid. The recipient is placed in an oven at 60°C, for 28 days. The unsafe materials lead to a high degree of corrosion of the metal samples [Thickett, 2004;Grzywacz, 2006].

Other methods of measuring pollutants use sensors that transform the contact with the gases into electric signal, like electrochemical sensors or semiconductors. The electrochemical sensors are made of two electrodes, inserted in an electrolyte, and united by a resistor. The electrolyte is separated from the environment by a Teflon membrane that allows gas to enter. It also has an activated charcoal filter that retains the unwanted gas. The electrodes used are a sensing electrode, whose material reacts with the gas by a red/ox mechanism, and a counter electrode. The current that passes through resistor is proportional to the gas concentration (ppm) [Göpel, 2008, http://www.intlsensor.com/pdf/electrochemical.pdf]. The electrochemical sensors are used for the detection of SO_2, NO_x, CO, O_3, and CH_2O.

The semiconductors have a sensitive layer made of metal oxides (SnO_2, VnO_5) that interact reversibly with the gases in the atmosphere, changing the resistance of sensors [Wöllenstein].

Microbalances with quartz crystal that have a metal plate made of silver or copper are used for corrosion monitoring in real time. They are very sensitive, detecting changes as small as 1 ppb [Grzywacz, 2006].

For a continuous measurement of microclimatic parameters and pollution, wireless networks can be used. They are made of small sensor nodes, each one of them containing a sensor part, a processor, memory, a wireless transceiver and a battery. The levels of pollutants are recorded by sensors, then processed with the help of memory and transmitted to the base station that receives information from all the sensor nodes. The disadvantages of the system are limited memory, low life battery, small range for transmission (few buildings). The advantages are small size (they don't distract the visitors), they don't need calibration, and they offer information in real time [Peralta, 2010; Raju, 2013].

Conclusions

There are many pollutants that can affect the museums' objects, but there are also many methods and techniques to monitor the presence and the concentration of damaging particles and gases. Although the costs may be a problem in some cases, the prevention of pollution and the preservation of entire collections of cultural goods are more important**.** The materials used for conservation or for display must be tested, to avoid the negative effects upon patrimonial objects.

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References:

Druzik, Cecily M. G. (1991) *Formaldehyde: Detection and Mitigation, WAAC Newsletter*, 13 (2), pp.13-16;

Göpel, W., Jones, T. A., Kleitz, M., Lundström, I., Seiyama, T. (2008) *Sensors, Chemical and Biochemical Sensors***,**vol 3, part II;

Grzywacz, Cecily M. (2006) *Monitoring for Gaseous Pollutants in Museum Environments*, The Getty Conservation Institute;

Hansen, A.D.A. (2000) *The Aethalometer*, Magee Scientific Company Berkeley, California, USA;

Hatchfield, Pamela (2004) *Pollutants in the Museum Environment: Practical Strategies for Problem Solving in Design, Exhibition and Storage***,** WAAC Newsletter 26 (2);

Lloyd, Helen, Grossi, Carlota M., Brimblecombe, P. (2011) *Low-technology dust monitoring for historic Collections*, Journal of the Institute of Conservation, 34 (1), 106 –116;

Moldoveanu. A. (2010), *Preventive conservation of cultural goods***,** Ed. Cetatea de Scaun, Târgovişte;

Nash, D.G., Leith, D. (2010) Use of passive diffusion tubes to monitor air pollutants. J Air Waste Manag Assoc. 60 (2) pp.204-209;

Nazaroff ,W. W. Ligocki, Mary P., Salmon, Lynn G., Cass, Glen R., Fall, Theresa, Jones, M.C., Liu, H.I.H., Ma, T. (1993) *Airborne Particles in Museums;*

Peralta, L.M. R., Brito, L.M.P.L., Gouveia, B.A.T., Sousa, D.J.G., Alves, C.S. (2010) *Automatic monitoring and control of museums' environment based on Wireless Sensor Networks***,** EJSE Special Issue: Wireless Sensor Networks and Practical Applications pp. 12-34;

Raju, P. V., Aravind, R.V.R.S., Kumar, B. S. (2013) *Pollution Monitoring System using Wireless Sensor Network in Visakhapatnam*, International Journal of Engineering Trends and Technology, 4(4) pp. 591-595;

Schieweck, Alexandra (2008) *Airborne Pollutants in Museum Showcases. Material emissions, influences, impact on artworks*, PhD thesis, Hochschule für Bildende Künste Dresden;

Slade, Sarah (2003) *Air Pollution,* Museums Australia Victoria;

Smolík, J., **Mašková, L.**, **Zíková, N.**, **Ondráčková, L.**, **Ondráček, J.** (2013) *Deposition of suspended fine particulate matter in a library*, Heritage Science Journal 1(7), pp. 1-5;

Targa, J., Loader, Alison (2008) *Tubes made of acrylic or polypropylene Diffusion Tubes for Ambient NO_2 Monitoring: Practical Guidance for Laboratories and Users;*

Tarnowski, Amber L., McNamara, C. J., Bearce, K. A., Mitchell, R., *Sticky Microbes and Dust on Objects in Historic Houses*, Objects Specialty Group Postprints, 11, The American Institute for Conservation of Historic & Artistic Works;

Tétreault, J., (1994) *Display Materials: The Good, the Bad and the Ugly*, From *Exhibitions and Conservation. Pre-prints of the Conference held at The Royal College of Physicians, Edinburg.* Ed. J. Sage, The Scottish Society for Conservation & Restoration (SSCR), Edinburg;

Thickett, D., Lee, L.R. (2004) *Selection of Materials for the Storage or Display of Museum Objects,* The British Museum Occasional Paper, 111;

Westby, D. (2011) *Basic Guide to Particle Counters and Particle Counter*, Particle Measuring Systems;

Wöllenstein, J., *Semiconductor Gas Sensors. Using Thin and Thick Film Technology*, Fraunhofer Institute for Physical Measurement Techniques;

Yoon, Y. H., Brimblecomb P. (2000) *Dust at Febrigg Hall*, The National Trust View, Issue 32, pp.31-32;

*** http://www.ormantineusa.com/

*** http://www.intlsensor.com/pdf/electrochemical.pdf (2008) *Electrochemical sensors* in *International Sensor Technology. Mountain View*, CA: IST, ch. 2, pp. 27–35;