The "MEMORI System"; Measurements, Effect Assessment And Mitigation of Pollutant Impact on Movable Cultural Assets. – Innovative Research for Market Transfer

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ABSTRACT

The EU project MEMORI (EU FP7-Supported Collaborative Project: 265132) provides conservators and stake holders with a user friendly tool to measure, analyse and evaluate in-situ indoor air quality (IAQ) for cultural heritage. The new portable MEMORI instrument and dosimeter measures the IAQ risk for degradation of heritage objects. Humidity, temperature, UV radiation and gaseous air pollutants affect the dosimeter as they do cultural heritage objects. Measurement values are uploaded to the MEMORI web-page where the results are presented. The user chooses the type of heritage material of interest and will get a "traffic light response". A red or yellow response shows that the material/object risks damage. The result values are also plotted in a two dimensional "acidic-oxidizing risk diagram" with green, yellow and red zones. The MEMORI web-pages give product information and guidelines for the use of the dosimeter. The web-pages also supply extensive information about recommended levels related to observed effects of gaseous pollutants on cultural heritage materials, and about methods to mitigate degradation caused by the atmosphere inside enclosures. Some major mitigation techniques that are considered are the choice of less emitting exhibition and storage systems and equipment, and the use of pollutant adsorbers and anoxia.

Keywords

Indoor air quality, dosimeter, MEMORI, cultural heritage, museums, preventive conservation

1. Introduction

"The MEMORI methodology" is a system for measurement of air quality and evaluation of related risk for degradation of indoor cultural heritage. The combined air pollution and climate load in an indoor location is assessed by exposing a sensitive dosimeter at location for a period of time and then measuring the effect in a small portable reader. The development of the dosimeter and reader in the MEMORI project makes air quality assessment for indoor heritage accessible for users locally. The conservator or other responsible person in a museum, library, archive or other location can expose dosimeters in indoor locations and then themselves measure the effect of the air quality with the dosimeter reader. The result will indicate the risk level for heritage materials of interest. Besides providing measurement instruments, MEMORI also provides a complete methodology for the evaluation of air quality risk to indoor heritage and suggested mitigation measures.

The methodology includes user guidelines, more detailed explanations of how the dosimeter is evaluated in relation to air quality risk to different heritage materials and suggestions for mitigation measures integrated with a decision support model to assist users to the most relevant measures.

2. The MEMORI measurement system

The MEMORI measurement instrument consists of a dosimeter (Figure 1: The MEMORI dosimeter, with the GSD (left) and EWO (right) glasses.1) which is exposed at the cultural heritage location of interest for 3 months and a dosimeter reader (Figure 2: The MEMORI dosimeter reader.2) which measures the effect of the air environment on the dosimeter.

Figure 1 The MEMORI dosimeter, with the GSD (left) and EWO (right) glasses.

Figure 2 The MEMORI dosimeter reader.

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The dosimeter holder, which is made of anodized aluminium, measures 90 mm x 25 mm x 4 mm. The holder includes two dosimeter pieces, a sensitive glass, the GSD (Glass Slide Dosimeter), and a sensitive synthetic polymer EWO (Early Warning Organic) (Figure 1: The MEMORI dosimeter, with the GSD (left) and EWO (right) glasses.1) which reacts to acidic and oxidizing air contaminants, respectively. In addition the dosimeter is sensitive to the climate factors, temperature, relative humidity and UV-light. The GSD measures the effect of especially organic acids, typically with indoor sources where as the EWO measures effect of "traffic pollutants" (nitrogen dioxide and ozone) that usually infiltrate from outdoors. Thus the dosimeter gives a response that represents the combined air pollution and climate load on the sensitive dosimeter materials. The MEMORI evaluation system correlates this measured effect with the degradation effect likely to be observed on different heritage materials to indicate the degradation risk for cultural heritage objects.

Separate measurements and evaluations of indoor air quality by the exposure of the GSD and EWO and subsequent analysis in the laboratories have been performed [1-4]. In MEMORI these two systems were integrated in an instrument (Figure 2: The MEMORI dosimeter reader.2) which was developed and built to measure the result in situ [5].

Important parts of the MEMORI system are the user guidelines and the technical user manual (Chapter 4) which will be available on the MEMORI web pages (Chapter 3). These documents will give valuable information before starting to use the MEMORI dosimeter and reader, and to accompany the use.

The air quality is registered by the MEMORI dosimeter by measuring the dosimeter before (the start point) and after exposure at location (see Chapter 4) in the MEMORI reader.

The MEMORI dosimeter reader is a portable selected wavelength instrument with the following dimensions: 224 mm x 164 mm x 82 mm. The instrument enclosure is made of anodized aluminium. The reader has three diodes on the front panel (Figure 2: The MEMORI dosimeter reader.2) which informs the user about the measurement sequence (M), if the battery is charged or needs charging (B) and if the clock needs adjustment (C). The detailed procedure of exposure of dosimeters, operation of the reader and measurement sequence is explained in the short user guideline, which also includes information about the conservation relevant concerns that should be considered when taking measurements.

3. The MEMORI web pages

The evaluation of results from using the MEMORI dosimeter and reader is performed on the MEMORI web pages. In addition, the MEMORI web pages also include separate pages with user guidelines, with information about air quality effects on the MEMORI dosimeter and how this relates to risk for different heritage materials and finally a decision support model and suggestions for mitigation measures to optimize preventive conservation.

The results values that are initially stored in the reader are uploaded directly to the MEMORI web pages on connecting the reader to a PC, then logging into the web pages and applying the "uploading software".

On the MEMORI web results pages the risk to heritage materials is represented by a simple "traffic light response" to the obtained measurement result. The MEMORI web result page no. 1 (Figure 3: The MEMORI web results page no. 1.3) shows the results of all uploaded measurements. The MEMORI web result page no. 2 (Figure 4: The MEMORI web diagrammatic results page no. 2.4) shows the results of selected measurements in an evaluation diagram. To get the traffic light response the end measurement must have been performed (if only the start measurement is available a "missing values" sign will be displayed) and the user must write a location description and select a material for the evaluation. The material selection is performed from a drop down menu and can be easily changed to evaluate the situation for different materials in the location. Results pages no. 2 gives a more detailed evaluation by plotting the selected results in two dimensions in a diagram which shows the result for the part of the dosimeter sensitive to acids (GSD) and to oxidation (EWO) along the vertical and horizontal axis, respectively. The diagram allows diagnosis if the likely reason for a high obtained result is indoor (most likely) sources of organic acids, which will give a high value on the vertical axis or if it is photo-oxidation due to external influences and infiltration from outdoor (most likely) which will give a high value on the horizontal axis. The diagram will also show if a measured value is close to a different risk category, e.g. if an obtained "yellow" is close to a high risk "red" situation.

The traffic light colour indication of risk for the different selected materials is based on a correlation of the known environmental, air quality and climate, response of the dosimeter as compared with that of the materials. E.g. for a material such as paper that is known to be quite sensitive to nitrogen dioxide, a response from the EWO part of the dosimeter (horizontal axis in Figure 4: The MEMORI web diagrammatic results page no. 2.4) signifies a comparable risk for degradation in the measured environment. The determination of final numerical levels for the colours signifying the risk levels for different materials in Figure 4: The MEMORI web diagrammatic results page no. 2.4 are not yet settled. However, although materials are sensitive to and degraded by some of the same influences from the air environment, the reaction mechanism for the degradation of different materials is different and there is some amount of uncertainty when the measured effect on the dosimeter is interpreted as a risk for degradation of a material. Higher values obtained from MEMORI measurements should therefore be interpreted as a deteriorating environment for preservation of indoor cultural heritage with indication of different risk levels for selected materials as shown by the traffic light evaluation.

4. User guidelines

The MEMORI user guidelines which will be available on the MEMORI web pages, describe why, where and when to measure pollutants in general, and in addition the decisions that need to be taken for effectively measuring pollutants are discussed. Information specifically about how to use the MEMORI dosimeter is included the guidelines.

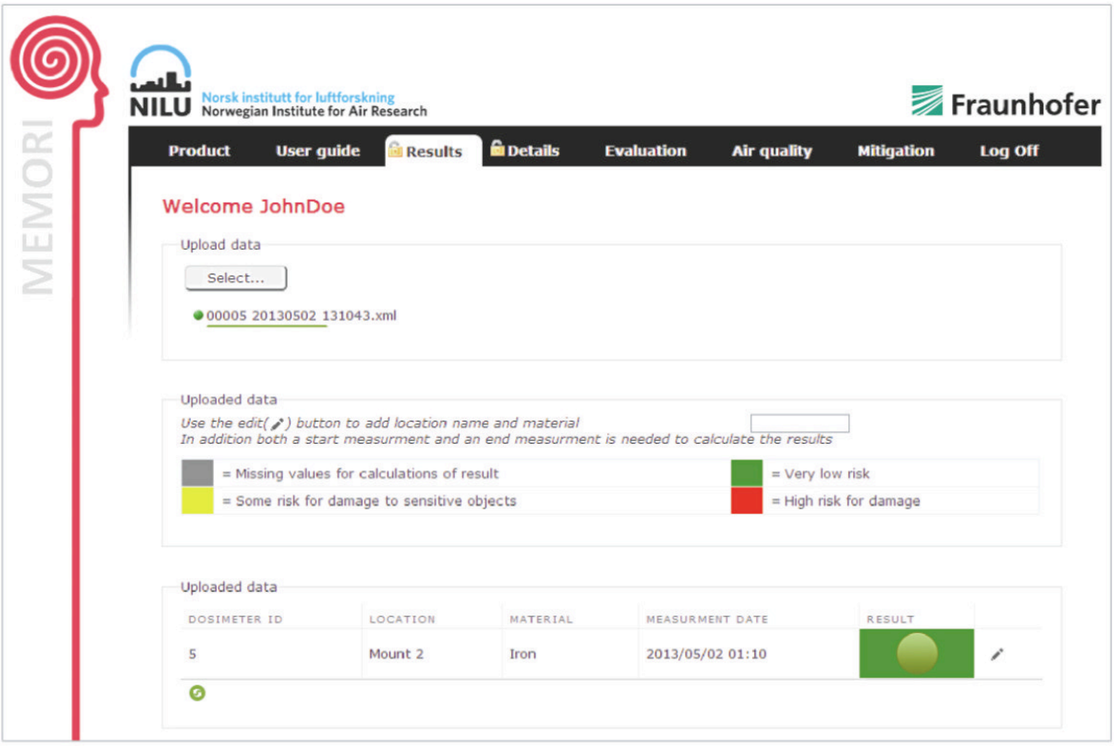

Figure 3 The MEMORI web results page no. 1.

The guidelines describe the risk of damage from the environment due to the effect of humidity, light and air pollutants on a variety of organic materials such as paper, textiles, leather, parchment (see Figure 5: Mounting of the MEMORI dosimeter in an enclosure at the Museum of Cultural History in Oslo, Norway.5), pigments and varnishes,

Figure 4 The MEMORI web diagrammatic results page no. 2.

and on inorganic materials such as metal and ceramics, in terms of the material sensitivity. The guidelines also give an overview of the most likely emissions, e.g. organic pollutants, from different construction materials typically used in protective enclosures. In addition more detailed information about the most common pollutants, their sources and what materials they can degrade is presented.

The guidelines give a short description of the types of methods that can be used to measure the air pollutants, they discuss the selection of measurement locations that may give the most useful results and how the timing of measurements during the year may affect the measurement results. A tool is provided that can determine the time period during the year when the maximum emission of acetic acid is expected. This can be used as a guide for when to measure organic pollutants, and to help understand how representative measurements are.

A separate short guideline and technical manual for the use of the dosimeter is provided. They describe the main conservation related concerns, how the dosimeter and reader should be handled and used and the technical properties related to the use: Each dosimeter has an identity number and a barcode on its reverse side (Figure 1: The MEMORI dosimeter, with the GSD (left) and EWO (right) glasses.1). The barcode is registered with the measurements in the MEMORI reader. The user must measure the start point (before mounting in location) and the end point (after demounting) for the three months exposure of each dosimeter. The reader is automatically activated on introduction of the dosimeter.

When measuring the start point, the user should describe the measurement location on the MEMORI web results page along with the identity number that is automatically registered on the page. It may in addition be useful to write down a short description of the monitoring sites in a notebook or the like for the later understanding of the dosimeter result. The dosimeter is active on both sides and it should be mounted in a stand for the airflow to circulate freely around it (Figure 5: Mounting of the MEMORI dosimeter in an enclosure at the Museum of Cultural History in Oslo, Norway.5).

Figure 5 Mounting of the MEMORI dosimeter in an enclosure at the Museum of Cultural History in Oslo, Norway.

A technical manual provides more detailed information about the information to the user given by the LED signals (M, B, C, Figure 2: The MEMORI dosimeter reader.2).

5. Air quality for cultural heritage materials

In the MEMORI web pages known pollutant interactions are described for materials of importance to cultural heritage. A description of pollutant damage is given, and where possible photographs of observed degradation included. For some materials degradation products are described, as analysis of these can sometimes indicate interaction with particular air pollutants.

Where known, threshold pollutant concentrations required for damage are shown, in relation to the MEMORI dosimeter (Figure 6: Diagram for threshold pollutant concentrations for lead in relation to the MEMORI dosimeter.6). The dosimeter response values in Figure 6: Diagram for threshold pollutant concentrations for lead in relation to the MEMORI dosimeter.6 are given as changes in adsorption coefficients for light at dosimeter specific wavelengths for the EWO and GSD. The absorption of light through the dosimeters after exposure at location increases with pollution load. This increase in absorption is measured by the MEMORI reader.

MEMORI response values GSD / EWO	Acetic acid (µgm^{-3})	Formic acid (µgm^{-3})	Nitrogen dioxide (µgm^{-3})	Ozone (µgm^{-3})
1.9 / 0.4	<400	<200	<3	<1.15
2.7 / 1.6	400-750	200-375	3-7.5	1.15-3
4.3 / 2.4	750-1500	375-750	7.5-15	3-6.5
7.5 / 3.8	1500-3000	750-1500	15-30	6.5-12.5
13.4 / 5.2	3000-6000	1500-3000	30-45	12.5-25
> 13.4 / > 5.2	>6000	>3000	>45	>25

Figure 6 Diagram for threshold pollutant concentrations for lead in relation to the MEMORI dosimeter.

As shown in the example above, for lead, this allows the results of the MEMORI dosimeter to be applied to different materials. Additional information is given where appropriate, for example known synergistic effects, and factors affecting sensitivity. This includes the influence of other environmental factors on pollutant damage, for example the relative humidity.

In general four main pollutants are included, acetic and formic acid, nitrogen dioxide and ozone. In the MEMORI project extensive research was performed to evaluate effects of acetic and formic acid on organic materials; varnishes, pigments (including inorganic), leather and parchment, paper and textiles. Results from these studies are included.

All known interactions with any pollutants are described, but where these occur with other pollutants, than the four mentioned above, little further information is given, - as the work has focussed on the pollutants measured by the MEMORI dosimeter.

6. Mitigation

The installation of movable cultural heritage assets in enclosures prevents degradation effects of external pollutants by changing the composition of the internal atmosphere. Enclosures with low ventilation prevent degradation effects of external pollutants, by allowing only very small amounts of the pollutants into the enclosures. However, an adverse effect of such enclosures is the accumulation of pollutants that are emitted from materials inside the enclosures. These internally emitted pollutants may be damaging to the objects. An important aim for preventive conservation strategy would be to reduce the amount of these internal pollutants as much as possible while maintaining the protective effect of the enclosure against the external pollutants. One control option that is sometimes observed is to ventilate the enclosure in a room where the amount of externally generated pollutants is reduced (by e.g. lowering the ventilation rate and/or mechanical filtration of the ventilation air to the room) [1]. Pollutants that are ventilated out of enclosures will then be substituted with the clean room air. However, it can be argued that this is to replace some of the intended functions of the enclosures with a second outer protective "shell", being the room.

Other control options are to reduce damaging emissions inside enclosures by using materials that are low emitting or do not emit hazardous substances [6,7] to cover emitting surfaces with protective air tight, e.g. aluminium, barrier films, or to reduce internal concentrations and impact fluxes to the objects by installing pollutant adsorbing materials. A combination of these methods are sometimes required to achieve the best possible effect. However the cultural heritage objects may themselves emit substantial amounts of contaminating substances both due to previous conservation treatments [8] and due to aging in which cases the use of adsorbers could be more important. For designers to construct and for users to choose the best possible enclosures it is important to know the chemical composition of the materials of the enclosure and objects, the type of emissions and the related expected degradation risk that are expected. Some studies of the capacity of materials such as zeolites and activated carbon to absorb contaminant gases have been performed to improve museum environments [9-11].

A long series of testing of emissions from construction materials used for protective enclosures for heritage objects and of the efficiency of different adsorbing media was performed in MEMORI [12,13].

The data obtained from measurements of air pollutants in museum enclosures, without and with adsorbers installed, was used to model the observed change in concentration of air pollutants inside the enclosures due to the inclusion of adsorbing media and to predict how this reduction in pollution load would depend on a changed ventilation rate for the enclosure. Activated carbon cloth was the most efficient of the adsorbing media tested, but experiments showed that the effect of the adsorbing media depended on the installation design, e.g. the application of cloth or other materials to cover the active carbon for aesthetical and protective reasons. 7 shows the effect of covering the bottom of an enclosure with a volume of 0.18 m^2 and height of only 18 cm with a 59 x 166 cm sheet of active carbon with the back of the cloth displayed.

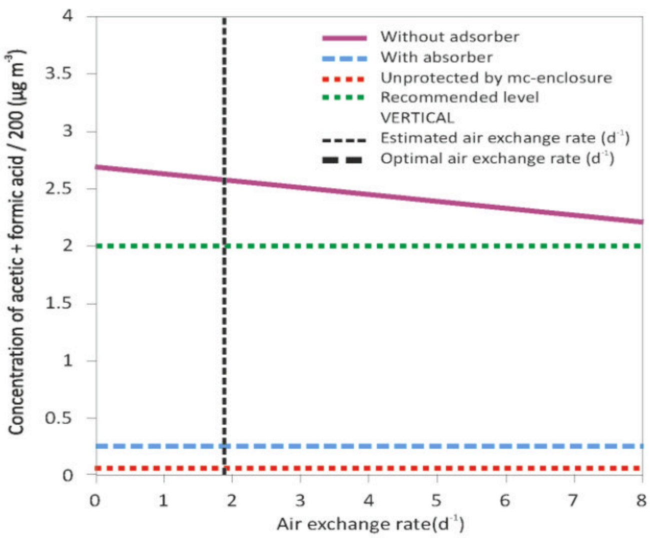

Figure 7 The concentration of acetic + formic acid inside an English Heritage enclosure with and without a cloth of active carbon adsorber installed. The vertical dotted line gives the measured values at the observed ventilation rate.

In MEMORI further testing, development and improvement of methods to measure oxygen levels in anoxic enclosures was also performed.

Through the MEMORI research better understanding has been reached about optimal mitigation methods that can be employed to improve the air quality if measured pollution levels are unacceptable, or a potential risk of damage has been identified. The MEMORI web pages will provide this information to the end users as a part of the recommended strategy to measure indoor air pollutants, evaluate the related risk for damage to heritage objects and implement the best measures to minimise the risk.

7. Conclusion

In the EU project MEMORI a dosimeter and adapted portable reader instrument that can measure the combined indoor impact of the major gaseous pollutants from external and internal sources has been developed and produced. Tested prototypes are available for application with heritage institutions and further research. The MEMORI system for measurement and evaluation of indoor air quality risk for cultural heritage includes web pages for the uploading, display and interpretation of measurement results. Measurements are interpreted as risk for degradation of materials of interest as selected by the user. The MEMORI web pages include user guidelines and extensive information about air quality risk to heritage objects and recommended mitigation measures.

For the benefit of future preventive conservation the MEMORI project has provided to the conservation community a new easy to use system for the measurement and evaluation of air quality for indoor heritage, new knowledge about degradation of organic materials and pigments and new knowledge about pollutant emissions from and the use of pollutant adsorbers in protective enclosures.

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