IAQ

15th International Conference on Indoor Air Quality in Heritage and Historic Environments

# Book of Abstracts

14 – 16 SEPTEMBER 2022 • LJUBLJANA, SLOVENIA

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# FOREWORD

Welcome to the 15th International conference on Indoor Air Quality in Historic and Heritage Environments.

2022 is still impacted by the Covid-19 pandemic, making traditional conferences with all participants attending in person virtually impossible, which is why we made the decision to organise the conference as a hybrid event. However, this does not come without its benefits, as we are now able to welcome many participants who otherwise would not be able to attend the conference due to their busy schedules, logistic and/or financial barriers. We are particularly grateful to those who managed to attend our conference in person. We are very much looking forward to seeing some familiar faces and making new connections.

We will do our best to make sure IAQ2022 continues the wonderful IAQ tradition of fruitful discussions with participants both online and in-person. During the three days the conference will host many interesting lectures and posters, which will also be presented as 5-minute oral presentations.

We hope those attending in person will enjoy their time in Ljubljana and look forward to hopefully seeing you all in person at the next IAQ.

Yours sincerely,
*Irena Kralj Cigić and Eva Menart*

University of Ljubljana, Faculty of Chemistry and Chemical Technology, the National Museum of Slovenia and E-RIHS.si, the European Research Infrastructure for Heritage Science Slovenia are organising the 15th **International Conference on Indoor Air Quality in Heritage and Historic Environments**. The conference is a forum for discussions on the influence of indoor air quality on objects in museums, libraries, and archives.

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# Wednesday, 14 September 2022

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| **12:00** | **Registration** |
| **12:50** | **Welcome: E. Menart** |
| **13:00** | **Session 1: Particles and other pollutants-Part I**<br>*Session Chair: J. Tétreault* |
| O1 | E. Monroe: Field air sampling and semi-quantitative GC-MS to examine and limit the risk of volatile organic compounds to collections |
| O2 | G. Eggert: Pollutants? Potash! |
| O3 | A. Kroflič: Particulate matter (PM) pollution in museum environments |
| O4 | I. Kraševec: Findings from a year-round monitoring of museum environment |
| **14:40** | **Coffee break** |
| **15:10** | **Session 1: Particles and other pollutants-Part II**<br>*Session Chair: J. Tetreault* |
| O5 | B. Sanchez: Indoor air pollutants in the National Archaeological Museum (MAN), Reina Sofía art gallery and a new proposal for the indoor air treatment |
| O6 | A. Alvarez-Martin: Integrating high-capacity sorptive extraction-gas chromatography-mass spectrometry as a preventive conservation tool at the Rijksmuseum |
| P1 | M. C. Canela: Effect of volatile organic compounds in indoor air on the stability of ultramarine blue paints |
| P2 | K. Deering: Exposure assessment of toxic metals and organochlorine pesticides among 28 employees of a natural history museum |
| P3 | E. Spiegel: Innovative (multi-)methods for the safe handling of biocide contaminated objects – The MUSA-project |
| **16:15** | **Session 2: Oddy and other tests**<br>*Session Chair: E. Menart* |
| O1 | D. Thickett: Using A-D strips and metal coupons for integrated pollution measurement |
| O2 | A. Jeberien: Accelerated corrosion testing for museums and collections – Oddy test reloaded, Part II |
| P1 | M. Catrambone: Assessment of air quality by diffusive sampling at the Museum of Art and Science |
| **17:15** | **End of Day 1** |

# Thursday, 15 September 2022

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| 9:00 | **Session 3: Enclosures, sorbents, display cases, active and intelligent packaging materials**<br>*Session Chair: O. Schalm* |
| O1 | J. Tétreault: Airtightness measurement of enclosures |
| O2 | P. Tignol: A new MOF paper sheet for air purification in cultural heritage institutions |
| O3 | J. Diehl: Evaluation of the preventive measures implemented to mitigate piperidinol pollutants inside the display cases of the Kunstkammer collection at the KHM Vienna — could we stop the evaporation process in the long term? |
| P1 | T. Kotajima: Selection of wood for museums based on its trend in chemical emission |
| P2 | M. S. K. Cheung: Detection and quantification of the emission of formic acid and acetic acid under in-situ storage and display environmental conditions in museum |
| P3 | E. Canosa: Field studies of new adsorbents for the capture of pollutants in cultural heritage environments |
| P4 | L. Barchi: Preventive conservation of display objects: improvements in testin case materials emissions |
| P5 | E. Mizutani: Air quality in the prefabricated temporary storage for the rescued cultural properties |
| 10:40 | **Coffee break** |
| 11:15 | **Session 4: Emissions from polymeric materials**<br>*Session Chair: T. Sawoszczuk* |
| O1 | T. Rijavec: The transport of plasticizers from PVC objects into the indoor environment |
| O2 | S. Da Ros: Partitioning behaviour of diethyl phthalate plasticiser in glass and aluminium surfaces |
| O3 | C. Vibert: Quantification of acids and chromophores in permanent paper upon accelerated ageing |
| O4 | A. Kravos: Emissions of volatile organic acids from lignin and resin acids |
| O5 | M. Novak: A quantitative study of the emission rates of acetic acid from the cellulose acetate objects |
| 13:20 | **Lunch break (free)** |

Day 2 continued on next page

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|---|---|
| **15:00** | **Session 5: Collection management**<br>*Session Chair: I. Kralj Cigić* |
| O1 | O. Schalm: Risk theories are a mess |
| O2 | D. Ribar: Interactive web applications for the dissemination of heritage science |
| O3 | C. Manfriani: IoT for sustainability and efficiency in preventive conservation at the Anthropology and Ethnology Museum of Florence |
| O4 | K. Krish: Balancing Air Exchange in the Face of Climate Change: Integrating Risks from Indoor and Outdoor-Generated Pollutants into HVAC Energy-Saving Strategies for Heritage Institutions |
| **16:40** | **End of Day 2** |
| **17:00** | **Visit and reception at the National Museum of Slovenia** |

## Friday, 16 September 2022

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| **10:00** | **Session 6: Smell-Part I**<br>*Session Chair: M. Strlič* |
| O1 | I. Leemans: Museums and smells. How to enhance the impact of cultural heritage collections through olfactory storytelling |
| O2 | C. Bembibre: New VOCs in the museum: balancing impact and value |
| O3 | E. Paolin: Olfactory exhibitions in museum environments. Developing a risk assessment methodology |
| **11:30** | **Coffee break** |
| **12:00** | **Session 6: Smell-Part II**<br>*Session Chair: M. Strlič* |
| O4 | T. Sawoszczuk: Whether the stench of mould could be a part of cultural heritage |
| O5 | V.-A. Michel: How to investigate smellscapes in heritage places using smellwalks and smell diaries |
| **12:50** | **Closing remarks: I. Kralj Cigić** |
| **13:00** | **End of Day 3** |

# ORAL PRESENTATIONS

# Field air sampling and semi-quantitative GC-MS to examine and limit the risk of volatile organic compounds to collections

IAQ Indoor Air Quality in Heritage and Historic Environments
LJUBLJANA, 14 — 16 SEPTEMBER 2022

K. Stoneburner[1], E. Monroe[1]*, F. France[1]

**1** Library of Congress, Washington DC, USA

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The materials used in the construction of collections storage areas, housings, and exhibition cases often release volatile compounds that can present certain risks to collection items. In addition, as collection materials age, they degrade and can often release particular odours, where the concentration and identity of these compounds can serve as an indicator of a collection's preservation needs. Some of these off-gassing compounds can accelerate not only the degradation of the object itself but also nearby collection objects. We have developed and applied several air sampling techniques, for use in the field or laboratory that utilize well-characterized sorbents and battery powered pumps. Collected compounds are later desorbed from the sorbent prior to separation and analysis by gas chromatography-mass spectrometry. The closed nature of the desorption-analysis process enables semi-quantitative analyses via comparison to an internal standard. Characterization of the air allows for a better understanding of the state of degradation of the collection item(s), risk posed to collections, and assist in developing mitigation or preservation strategies. This presentation will detail the methodologies and parameters used by the Library and illustrate, through several case studies, how this testing regimen has assisted in understanding the current state of degradation, potential risks to the Library of Congress's collections, as well as informed the selection of appropriate mitigation techniques.

**▶ Keywords:**
**materials emissions, gas chromatography-mass spectrometry, air sampling, volatile organic compounds**

Notes:

# Pollutants? Potash!



G. Eggert[1]*, A. Fischer[1], J. Stelzner[2]

**1** State Academy of Art and Design, Stuttgart, Germany
**2** Römisch-Germanisches Zentralmuseum, Mainz, Germany

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Saturated solutions of soluble salts are used since decades to achieve constant humidity in display cases. Do they also absorb pollutants? According to Henry's law, every compound in the air will maintain an equilibrium and dissolve in an aqueous phase, so the concentration in the air is lowered!

Formaldehyde is a ubiquitous indoor air pollutant from many sources. It has a special role in the degradation of historic glasses. By reaction with humidity (ion exchange), alkaline surface films are formed. Absorbed formaldehyde reacts directly to formate via the Cannizzaro reaction. Indeed, formate and not carbonate (from carbon dioxide) is often the dominant anion on glass. As electrolytes, these salt containing films induce corrosion in contact to metal (GIMME=glass-induced metal-corrosion on museum exhibits [1]). Special copper and zinc formates are formed on copper alloys (incl. brass). Otherwise (no glass contact), metal formates are rarely found [2].

Lowering the relative humidity helps to reduce glass and metal corrosion. The acceptable lower limit to avoid crizzling of the gel layer on glass is given as 35-42% RH in the literature. A display case climatisation with saturated potassium carbonate ('potash') solution (43%) is on the safe side, but not magnesium chloride (33%). Indeed, GIMME model experiments in desiccators with formaldehyde found that the visible occurrence of corrosion products can be slowed down considerably with a potash solution compared to higher RH.

A concentrated potash solution is alkaline (pH 11.3), dissolved formaldehyde should react to formate. Test measurements at the Fraunhofer WKI Braunschweig proved magnesium nitrate (54%) and potash solutions to be excellent absorbers for formaldehyde, potash absorbing even faster. Both solutions maintain a RH nearly independent of room temperature (see table) and evolve no harmful gases (Oddy test, thermodynamic calculations), in opposite to magnesium chloride (33%). Tests with other relevant acid pollutants (acetic and formic acid, $NO_x$, $SO_2$) in Saarbrücken are planned, the acids should be 'neutralised' by potash [3].

Two in one go: constant RH and universal absorption of corrosive pollutants? It seems possible, let's see! Partners to test potash solutions in display cases wanted!

RH OF SATURATED SALT SOLUTIONS AT VARIOUS TEMPERATURES

| Compound | Formula | 15 °C | 20 °C | 25 °C | 30 °C |
|---|---|---|---|---|---|
| Potassium carbonate | $K_2CO_3$ | 43.2% | 43.2% | 43.2% | 43.2% |
| Magnesium nitrate hexahydrate | $Mg(NO_3)2 \cdot 6H_2O$ | 55.9% | 54.4% | 52.9% | 51.4% |

**Keywords:**
**display cases, formaldehyde, glass-induced metal corrosion, pollutant absorption, saturated salt solutions**

**[1]** A. Fischer, G. Eggert, R. Dinnebier, T. Runčevski, *When Glass and Metal Corrode Together, V: Sodium Copper Formate*, Studies in Conservation, 63 (2018), 342–55.

**[2]** G. Eggert, A. Fischer, *The formation of formates – a review of metal formates on heritage objects*, Heritage Science, 9 (2021).

**[3]** G. Eggert, *Saturated salt solutions in showcases: humidity control and pollutant absorption*, Heritage Science, 10 (2022), in print.

## Notes:

# Particulate matter (PM) pollution in museum environments

A. Kroflič[1]*, U. Skube[1], K. Vidović[1], E. Menart[2,3]

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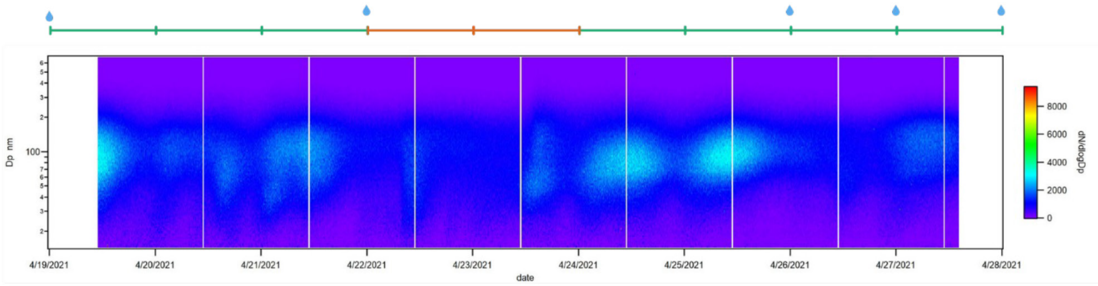
Air pollutants cause material degradation and loss. While outdoors, they act in combination with changing meteorological conditions (weathering), air quality and conditions in museum rooms are usually much more controlled. Nevertheless, optimal climate for specific heritage objects cannot always be ensured.

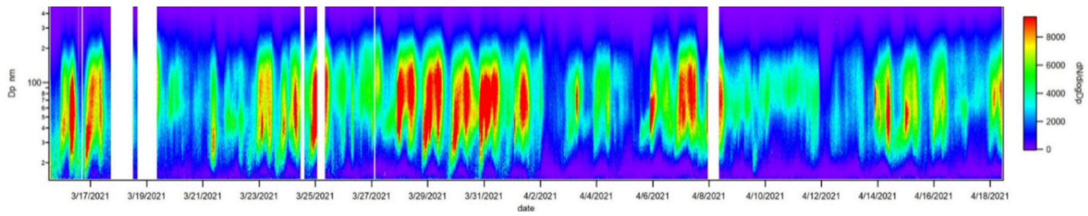
We investigated air quality with an emphasis on particulate matter (PM) in two museum rooms, both belonging to the National Museum of Slovenia. The first one is a museum repository of archaeological objects, which is air conditioned and strictly controlled in terms of visitors and air humidity. The second space is a Roman lapidarium with stone monuments, adjacent to the main museum building. The lapidarium is a nonhermetic glasshouse, freely open to visitors, and thus prone to air pollution from outdoors. Although the exhibited stones in the lapidarium are protected from rainfall and wind erosion, the room is not air conditioned, which can even potentiate the influence of outdoor air pollution once it gets captured in a closed unventilated room.

The museum is situated in the city centre of Ljubljana, which means an urban environment. According to the recent risk assessment analysis, atmospheric $NO_x$ in combination with ozone producing $HNO_3$ represent the major threat to calcareous stone heritage in Ljubljana in recent years [1]. The second major detrimental effect, however, is predicted due to PM pollution, whose modes of action are largely unknown.

PM pollution was thus continuously monitored in both places by a scanning mobility particle sizer (TSI-SMPS Spectrometer, 3936L75) in late summer 2020 and spring 2021 (repository), and in late spring 2020 and early spring 2021 (lapidarium). In the repository, the air turned out to be relatively clean with respect to PM (peaks at approx. 2500 particles of 100 nm size), while PM pollution in the lapidarium shows comparable pollution to outdoor exposures (peaks at around 5000 particles of 60 nm size) and limits protection of exhibited objects. PM pollution in the lapidarium will be further correlated with outdoor air pollution and risk for exposed historic objects will be assessed.

## CONTOUR PLOTS SHOWING PM POLLUTION IN SPRING 2021: REPOSITORY (TOP) AND LAPIDARIUM (BOTTOM).




This work was supported by the Slovenian Research Agency (research core funding Nos. P1-0034 and P6-0283, and project grant J1-1707 ‘Impacts of PM Pollution on Cultural Heritage’).

▶ **Keywords:** calcareous stones, ceramics, PM pollution, museum repository, lapidarium

**[1]** A. Kroflič, K. Vidović, E. Menart, *Air pollution as a risk to cultural heritage in Slovenia*, Varstvo spomenikov, in press.

## Notes:

Indoor Air Quality in Heritage and Historic Environments
LJUBLJANA, 14 — 16 SEPTEMBER 2022

# Findings from a year-round monitoring of museum environment

I. Kraševec[1]*, I. Kralj Cigić[1], M. Strlič[1,2,3]

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For a year, we followed the microenvironment in 7 heritage institutions of different sizes across Europe. Using a comprehensive monitoring plan, we aimed to compare seasonal measurements of pollutants ($NO_2$, $SO_2$, acetic acid, formic acid, formaldehyde, acetaldehyde), temperature and relative humidity both inside and outside object enclosures and display cases. Commercially available passive samplers and a recently developed and validated method for the determination of acetic and formic acid were used [1].

The determined concentrations ranged from respective LODs (limits of detection) to over 9000 μg/m$^3$ for acetic acid, 812 μg/m$^3$ for formic acid, 251 μg/m$^3$ for formaldehyde, 29.7 μg/m$^3$ for acetaldehyde and 39.6 μg/m$^3$ for $NO_2$, while $SO_2$ was not detected above LOD in any location. The measured temperatures ranged from 10.7 to 28.9 °C, and relative humidity ranged from 42.9 to 75.2% across the year.

The investigated microenvironments were found to vary greatly between institutions as well as the selected locations. Significant differences were observed between storage and display environments, and between rooms and enclosures, which can be attributed to parameters such as environment volumes, ventilation, the density of objects and the materials present. In buildings where no mechanical air control (HVAC) was implemented, seasonal variations in pollutant concentrations were observed. Finally, in several locations with the environmental parameters exceeding international recommendations, possible causes and solutions were suggested.

This work was part of the project APACHE “Active & intelligent PAckaging materials and display cases as a tool for preventive conservation of Cultural Heritage,” European Union’s Horizon 2020 research and innovation programme under grant agreement No. 814496.

The authors would like to thank the following personnel and their respective institutions for performing sampling in collection locations: A. Giatti, L. Pensabene, S. Divari, M. I. Pierigè, E. Mátyas, T. Somfai, E. Menart, V. Sorano-Stedman, A. Roche, E. Kissel.

**Keywords: monitoring, pollutants, passive sampling, display case, storage environment**

**[1]** I. Kraševec, E. Menart, M. Strlič, I. Kralj Cigić, *Validation of passive samplers for monitoring of acetic and formic acid in museum environments,* Heritage Science 9(1) (2021).

# Notes:

# Indoor air pollutants in the National Archaeological Museum (MAN), Reina Sofía art gallery and a new proposal for the indoor air treatment

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**3** Aire Limpio Group, Madrid, Spain

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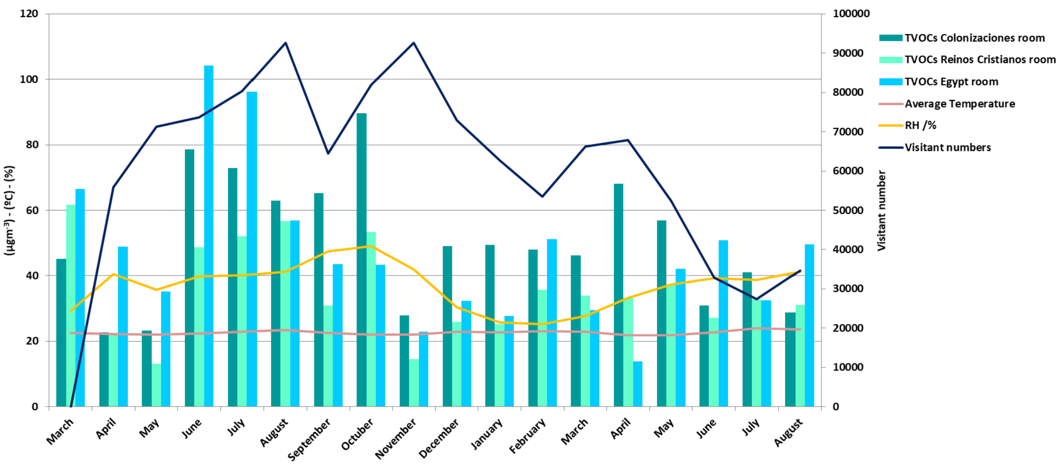
This presentation summarizes the results obtained by systematic monthly sampling over four years in both museums [1]. The samplings were carried out on consecutive days with museums closed and open to the public, indicating the effect of human presence on indoor air quality.

The sampling at the National Archaeological Museum began after a thorough refurbishment. This fact made it possible to determine the construction materials emission. The new showcases in which most artworks are exhibited were also studied. Samples of both VOCs and bioaerosols (bacteria and fungi) were evaluated for comparison, outside the museum, inside the museum (different rooms) and inside different display cases.

On the other hand, the Reina Sofia Museum, years after its opening, exhibits a large pictorial sample in more diaphanous rooms with practically no showcases. The sampling was made outdoors in different interior rooms and the inner courtyard of this museum.

### TOTAL VOLATILE ORGANIC COMPOUNDS IN DIFFERENT ROOMS AFTER THE MAN´S OPENING AND RELATED TO TEMPERATURE, HUMIDITY AND VISITANT NUMBERS.



**Keywords:** indoor air pollutants, VOCs, showcases, heritage conservation, air treatment

**[1]** B. Sánchez, M. Oliveira, O. Vilanova, M. Canela, *Volatile Organic Compounds in the Spanish National Archaeological Museum: Four Years of Chemometric Analysis*, Building and Environment, 174 (2020), 1–9.

## Notes:

# Integrating high-capacity sorptive extraction-gas chromatography-mass spectrometry as a preventive conservation tool at the Rijksmuseum

Indoor Air Quality in Heritage and Historic Environments
LJUBLJANA, 14 — 16 SEPTEMBER 2022

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Fingerprinting volatile organic compounds (VOCs) is a promising diagnostic method to anticipate unwanted chemical reactions that can alter priceless artworks housed at museums [1].

The Preventive Conservation Group of the Rijksmuseum has the mission to implement protocols that maximize the quality and quantity of information extracted from each sample while the analysis remains non-destructive, and is barely perceptible to the visitors.

The main objectives of our current research are: (i) to implement state of the art sampling tools for the screening of VOCs, and (ii) to monitor the presence of specific groups of analytes accumulated within museum showcases and storage enclosures.

With this aim, a very sensitive and semi-automated high-capacity sorptive extraction technique (HiSorb), coupled with gas chromatography-mass spectrometry (GC-MS), has been optimized for sampling and analyzing VOCs accumulated in enclosed spaces at the Rijksmuseum. For the first time, two recently commercially available HiSorb probes were tested, and their performance was compared with the complementary solid phase microextraction (SPME) fibers. Additionally, three GC-MS methods have been optimized in order to increase the sensitivity of detection of small carboxylic acids and sulfur compounds.

The difference in selectivity between HiSorb and SPME was evident and highlights the importance of using the correct sampling technique, in combination with the appropriate separation and detection GC-MS method. The combination of sampling probes and separation methods developed in this study allow us to perform general screenings or to target specific analytes.

The new methodology presented in this study integrates sampling, extraction, concentration and sample introduction to an analytical instrument into one solvent-free step. The final addition is to automate part of the workflow to replace time consuming passive sampling strategies while working more effectively and reducing instrumental variables.

By implementing these new sampling strategies in the workflow of the Rijksmuseum, the Preventive Conservation Group expects to improve conditions for storage and display of sensitive objects, and foster better communication between conservators, curators and scientists about preventive care.

**Keywords: preventive conservation, volatile organic compounds, gas chromatography, solvent-free extraction methods**

**[1]** C. M. Grzywacz, *Monitoring for Gaseous Pollutants in Museum Environments*, Getty Publications (2006).

## Notes:

# Using A-D strips and metal coupons for integrated pollution measurement

IAQ Indoor Air Quality in Heritage and Historic Environments
LJUBLJANA, 14 — 16 SEPTEMBER 2022

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Measuring and hence assessing and mitigating pollution has been limited in many collections due to the high costs and technical requirements. Surveys of conservation professionals also highlighted a lack of training and confidence in the pollution area as a major obstacle.

Acetic acid is the most commonly reported cause of deterioration to cultural heritage in enclosures. A-D strips have been proposed as a simple, accessible method to indicate acetic acid concentrations (in enclosures), using a colorimeter. The strips need very fast measurement and many smaller institutions do not own colorimeters. Two sets of printed colour strips have been developed. One to use to calibrate mobile phones or scanners for assessing exposed A-D strips. A second, to allow coarser visual assessment, to within 6 classes. The effects of formic acid at different RH levels and of light exposure on A-D strip response have been recently elucidated. Some questions remain about the method: what is the impact of the weaker industrial gases such as nitrogen oxides, can the light sensitivity be accommodated with a simple open opaque enclosure and what is the exact period the strip indicates? These have been investigated in a series of experiments. When measuring the strips, it is clear they give a reading indicative of the strong acid concentration averaged over the last few hours in the enclosure. Many enclosure environments have fluctuating concentrations and very many readings would be required to characterise them. A simple tool to assess the diurnal to seasonal effect on acetic acid concentrations has been developed to aid planning and interpreting measurements. Longer term methods based on lead coupons will be described. For certain collections, sulfide gases are important and silver coupons with colorimetry have been developed to measure these. A spreadsheet has been written to convert the measured L* value into an estimated silver sulfide layer thickness and place the results into the ISO 11844 classes [1].

The MEMORI assessment model (previously presented) has been adapted to incorporate A-D strip and silver coupon results [2]. From the surveys and numerous enquiries it is clear that assessing the concentrations measured is not straightforward. The literature is dispersed, much of it grey literature and can be contradictory and confusing. The model draws together data from 3000 references and unpublished results to allow ready risk assessment.

**Keywords: acetic acid, A-D strips, silver**

**[1]** ISO 11844-2:2020 Corrosion of metals and alloys — Classification of low corrosivity of indoor atmospheres — Part 2: Determination of corrosion attack in indoor atmospheres, ISO, Geneva.

**[2]** English Heritage, (10 mar 2021) https://www.english-heritage.org.uk/learn/conservation/collections-advice-and-guidance/ MANAGEMENT OF SHOWCASES.

## Notes:

# Accelerated corrosion testing for museums and collections – Oddy test reloaded, Part II

IAQ Indoor Air Quality in Heritage and Historic Environments
LJUBLJANA, 14 — 16 SEPTEMBER 2022

A. Jeberien[1]*, S. Schaffarczyk[1], N. Alktash[2], B. Szyszka[2]

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The impact of pollutants on collections is a long-recognized problem in heritage conservation. Especially, the vast variety of new material used in building and display construction challenges the preservation of collections. While control strategies given in guidelines (EN 16893, 15999-1) or in the literature [1] are rather precise, options for analytical methods vary from intense laboratory examination to more simple accelerated corrosion and spot tests, though often leading to discussion on results and interpretation.

HTW Berlin's *Material-Checker* project (MAT-CH) explores the most common corrosion test, known as the Oddy test. It is based on the reaction caused by volatile organic compounds on silver, copper and lead under accelerated conditions, like high humidity and elevated temperatures [2]. Despite many years of successful application, the test's validity must be strongly questioned due to inconsistent equipment, varying procedures, and a subjective evaluation method. Therefore, MAT-CH project reviews test equipment and procedures, thus aiming for a higher applicability, reliability, and sustainability.

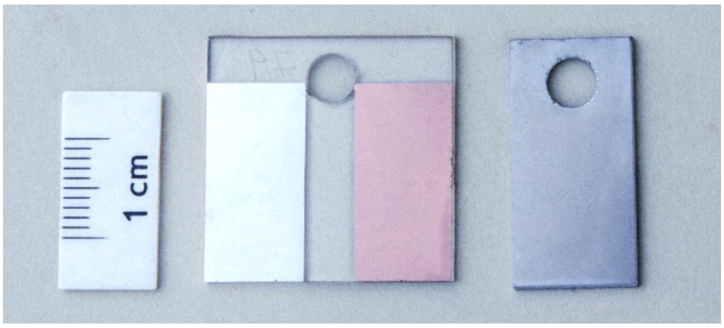
After improvements on the reaction vessel [3], the second project phase (2020-2022) focused on ready-to-use and reproduceable indicator plates (figure). Machine-made and thin metal coated on borosilicate Corning® glass, MAT-CH indicators are more precise than the manually prepared bulk metal coupons. Both innovations, the vessel and the indicators, simplify the test set-up and streamline application procedures. After all, MAT-CH equipment contributes to a reduction of valuable resources.

The novel indicators were developed in cooperation with Technical University Berlin (TU). Research preparations included the adaption of coating devices, shadow masks and metal targets. Furthermore, the glasses needed to be cut to size and drilled for hanging application. Since TU Berlin's expertise derives from a rather industrial sector, research included several coating series for the evaluation of basic parameters, like power, dynamics, and pulse mode. The coating was accompanied by instrumental analysis exploring and clarifying layer thickness, homogeneity, density and adhesion of the metal layers. Eventually, applicable prototypes were selected to be further explored regarding general corrosion and overall functionality behavior.

Both, the corrosion, and functionality test were carried out under accelerated conditions and in a comparative setting of MAT-CH and Oddy equipment. Known materials, like foam board or vulcanized rubber, were chosen on the basis of multiple pre-testing, and differing corrosion potential. Especially the functionality test indicated a significant behavior and high sensitivity of MAT-CH indicators. Furthermore, the tests showed homogenous, but specific corrosion patterns for each metal and test material. Finally, instrumental analysis confirmed a high comparability and equal corrosion behavior for both settings, MAT-CH and Oddy test. Nevertheless, tests also have indicated the necessity for further optimization and refinements, especially on lead indicators.

For the continuation of research, MAT-CH team currently applied for a follow-up project, thus hoping to complete the test setting, including a reliable evaluation method of results.

FRESHLY COATED MAT-CH INDICATOR PLATES: SILVER, COPPER AND LEAD (F.L.T.R.)




**Keywords: preventive conservation, pollutants, VOCs, corrosion testing, Oddy test**

**[1]** J. Tétreault, *Control of Pollutants in Museums and Archives*, CCI Technical Bulletin 37 (2021).

**[2]** A. W. Oddy, *An Unsuspected Danger in Display*, Museums Journal 73:1 (1973), 27–28.

**[3]** H. Heine, A. Jeberien, *Oddy Test Reloaded: Standardized Test Equipment and Evaluation Methods for Accelerated Corrosion Testing*, Studies in Conservation 63:sup1 (2018), 362–365.

# Airtightness measurement of enclosures

IAQ Indoor Air Quality in Heritage and Historic Environments
LJUBLJANA, 14 — 16 SEPTEMBER 2022

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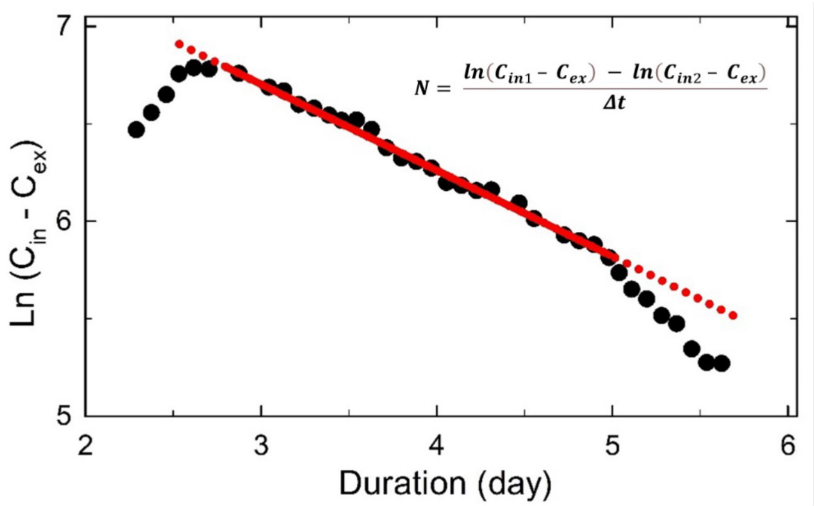
The purpose of this presentation is to explain the advantages of airtight enclosures for the display and storage of heritage collections and to outline a methodology for assessing their performance. Well-sealed enclosures produce tighter environmental tolerances, which can often enhance the preservation of vulnerable objects at a moderate cost. They provide a very effective and sustainable solution for the improved control of agents of deterioration, such as relative humidity and dust infiltration. A high level of airtightness will reduce inward and outward air movement through leakage points and limit gas diffusion through the enclosure envelope. This performance characteristic is often measured as the rate of loss of a tracer gas, most commonly carbon dioxide ($CO_2$), from an enclosure. Over the past decade, $CO_2$ monitoring data-loggers have become more affordable and easier to use for this task. As a result, determining the airtightness of display cases and other enclosures has become increasingly accessible for the heritage community.

$CO_2$ DECAY IN AN ENCLOSURE EXPRESSED AS THE NATURAL LOGARITHM OF $CO_2$ CONCENTRATION MINUS THE EXTERNAL VALUE IN THE ROOM AS A FUNCTION OF TIME. N IS THE AIRTIGHTNESS (1/DAY).



Leakage mechanisms will be explained along with a protocol for evaluating airtightness based on the multi-point concentration decay method. Several case studies will be used to highlight influencing factors for airtightness determination: internal air cavities (e.g. two-part display case), the use of a fan for circulating air, and the presence of sorbent materials. A scenario will also be described where a high level of airtightness may not be appropriate for the preservation of a lead object in an enclosure containing oak.

**Keywords: airtightness, leakage, protocol, specification**

## Notes:

# A new MOF paper sheet for air purification in cultural heritage institutions

Indoor Air Quality in Heritage and Historic Environments
LJUBLJANA, 14 — 16 SEPTEMBER 2022

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In recent decades, the harmful effects of volatile organic compounds (VOCs) on cultural heritage materials in confined spaces (showcases, cabinets, storage boxes) have been investigated. Passive air filtration is considered a benchmark to avoid the contact of these vapours with the artefacts. The adsorbents generally chosen belong to the class of porous materials such as activated carbons and zeolites. However, these adsorbents are usually not selective, difficult to regenerate and can release pollutants at room temperature which calls for new adsorbents. MOFs (Metal-Organic Frameworks), a recent class of hybrid, porous crystalline materials, have been proposed recently for this application. Their highly tuneable character is of interest to develop selective sorbents for the capture of VOCs. Perfluorinated hydrophobic MOFs have shown very interesting results for the selective capture of acetic acid in the presence of moisture (CNRS patent filed in 2018) [1]. Although, these materials remain still expensive, some of us have recently proposed the use of cheaper and scalable MOFs with identical performances (CNRS patent filed in 2022). As these materials are produced in powder form, it is necessary to shape them for a practical use in Heritage institutions. Granules or beads can easily be produced, but they might release powder if their mechanical stability is not sufficient, thus requiring a careful handling and a container to hold them. We propose a new green formulation process relying on the use of a cellulose-based matrix to produce paper sheets loaded with an exceptionnal high loading of porous solids (> 70%wt), MOFs, zeolites or carbons, while retaining good mechanical properties (CNRS patent filed in 2022) [2]. The ability of the paper membranes and their capacity to capture different VOCs such as organic acids (formic, acetic and acrylic acid) and furfural was then tested. For this purpose, a set-up comprising an exposure chamber and a photoionisation detector was developed. Remarkably, the MOF composites were found to be more efficient than the activated carbon and zeolite ones, reaching a total VOC sorption capacity of over 200 mg of VOCs per gram of membrane. After capture, the amount of VOCs released by the membranes was measured using passive diffusion tubes. Unlike activated carbons or zeolite composites, the MOF membranes did not release the adsorbed pollutants during the tests, highlighting their potential for indoor air quality applications.

**Keywords:** VOCs, capture, Metal-Organic Frameworks, paper membranes

**[1]** K. Dedecker, R. S. Pillai, F. Nouar, J. Pires, N. Steunou, E. Dumas, G. Maurin, C. Serre, M. L. Pinto, *Metal-Organic Frameworks for Cultural Heritage preservation: the case of acetic acid removal*. ACS. Appl. Mater. Interfaces, 10, 16 (2018), 13886–13894.

**[2]** BNT232800FR00. *High porous materials loading in membranes* (2022).

## Notes:

IAQ Indoor Air Quality in Heritage and Historic Environments
LJUBLJANA, 14 — 16 SEPTEMBER 2022

# Evaluation of the preventive measures implemented to mitigate piperidinol pollutants inside the display cases of the Kunstkammer collection at the KHM Vienna — could we stop the evaporation process in the long term?

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The Kunstkammer collection of the Kunsthistorisches Museum Vienna (KHM) reopened in 2013 after undergoing a ten-year reinstallation project. As mentioned for the first time at the IAQ-conference in Prague (2014) and presented in detail at the IAQ-conference in Birmingham (2016), there already were issues with the appearance of white, milky or crystal deposits on surfaces of objects after only a few months after the reopening. The pollutants, which were so far completely unknown in the museum sector, were identified as penta-methyl-piperidinol (PMP) and tetra-methyl-piperidinol (TMP) and a MS-polymer sealant of the showcases was determined as the source of this emission. In the meantime, it has become known that similar phenomena were observed simultaneously or somewhat delayed in numerous international museums and that various mitigation strategies were developed [1,2].

The Kunsthistorisches Museum Vienna has chosen the approach of active air filtration for the mitigation of pollution in the showcases. The upgrade of active air filtration with suitable sorbent materials has proved to be effective in decreasing the piperidinol concentrations significantly. Initially, the interval for changing the filter material was set relatively narrow. Considering the carbon footprint by long transport distances, high costs and high energy consumption, the intervals have meanwhile been greatly extended and will hopefully soon become unnecessary.

The effectiveness of the air purifying devices and the extension of the filter changing intervals were constantly monitored using various analytical methods. At the beginning, the samples were taken from the surface of artefacts by filter paper and after their extraction, the extracts were analysed by gas chromatography-mass spectrometry technique (GC-MS) to prove a possible presence of piperidinols. When the appearance of milky film deposits on surface of various art objects was very much minimalized, another step of monitoring was introduced using solid phase micro extraction (SPME) technique for the air sampling subsequently combined with GC-MS to identify the pollutants in the inner atmosphere of the showcases from the SPME fibers [3]. This procedure enables us to avoid any direct contact with the objects and helps to identify possible pollutants in the air prior their condensation on the surface of the artefacts. The initial results of this preventive screening are showing negative presence of pollutants (not just piperidinols but also other VOCs) inside of the showcases so far, what keeps us optimistic is that the efficiency of the upgraded filtration system could be adequately sufficient for longer period and enabling us to prolong their lifespan and then also reduced the related costs in the future.

**Keywords: museum showcases, filters, piperidols, GC-MS, SPME**

**[1]** J. van Iperen, H. van Keulen, K. Keune, K. Abdulah, R. van Langh, *Crystalline Deposits in New Display Cases at the Rijksmuseum: Characterisation and Origin*, Studies in Conservation, 66:5 (2021), 253–271.

**[2]** virtual zoom meeting: TMP-ol Volatiles and Efflorescence Mitigation project Meeting, hosted by the Smithsonian´s National Museum of American Indian and the Smithsonian´s Museum Conservation Institute; 7-9.7.2020 as part of the collaborative TMP Volatiles and Efflorescence Mitigation Project funded by the SI National Collections Program (NCP) Collections Care Initiative.

**[3]** A. Alvarez-Martin, J. George, E. Kaplan, L. Osmond, L. Bright, G. A. Newsome, R. Kaczkowski, F. Vanmeert, G. Kavich, S. Heald, *Identifying VOCs in exhibition cases and efflorescence on museum objects exhibited at Smithsonian's National Museum of the American Indian-New York,* Heritage Science 8 (2020), 115–127.

## Notes:

# The transport of plasticizers from PVC objects into the indoor environment

IAQ Indoor Air Quality in Heritage and Historic Environments
LJUBLJANA, 14 — 16 SEPTEMBER 2022

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Historically, phthalates have been widely used as plasticizers for poly(vinyl chloride) (PVC), but are being currently replaced by non-phthalate alternatives, such as dioctyl terephthalate (DOTP) and diisononyl 1,2-cyclohexane dicarboxylate (DINCH) due to health concerns [1]. High molecular weight phthalates, such as di(2-ethlyhexyl) phthalate (DEHP), diisononyl phthalate (DINP) and diisodecyl phthalate (DIDP) are popular plasticizers found in common museum and private collections [2]. Plasticizers are classified as semi-volatile organic compounds (SVOCs). They are present in the indoor air and prone to depositing on exposed surfaces and on particulate matter [3]. Historic and contemporary PVC objects can contain substantial amounts of plasticizers (up to 50%) and presents a notable source of SVOCs.

This work focused on investigating the loss of plasticizers from PVC objects at controlled environmental conditions. The effect of temperature (50 °C – 80 °C), humidity (30% – 80%), and air velocity (0.0 m/s – 0.8 m/s) on the plasticizer loss was investigated by exposing sacrificial samples with four different plasticizers (DEHP, DOTP, DIDP and DINCH) to accelerated degradation for 2 months. Plasticizer loss was monitored by gravimetry and gas chromatography. The results revealed that temperature had the most prominent effect on plasticizer loss, followed by air velocity. Additionally, it was observed that objects with DEHP exhibited a higher loss of plasticizer than DOTP or DINCH. The mechanism of loss was controlled by diffusion for most samples, although some were evaporation-controlled. The loss of plasticizers from PVC objects presents a danger to collections at two levels. Firstly, as damage to the object itself, causing brittleness and possible structural failure. Secondly, the emitted plasticizers are released into the indoor air and deposited on surfaces of nearby objects, thus contaminating them.

The results of this study allow us to assess the risk of plasticizer loss according to the environmental conditions in a collection. It provides an insight into the transport of plasticizers from PVC heritage objects, which can aid in optimizing storage conditions. The resulting trends will be further used in modelling the loss of plasticizers from PVC, as well as investigating possible sinks for the contaminants.

**Keywords: plasticizers, phthalates, PVC, migration, heritage science**

**[1]** U. Heudorf, V. Mersch-Sundermann, J. Angerer, Phthalates: *Toxicology and exposure,* Int J Hyg Environ Health, 210 (2007), 623–634.

**[2]** T. Rijavec, D. Ribar, J. Markelj, M. Strlič, I. Kralj Cigić, *Machine learning-assisted non-destructive plasticizer identification and quantification in historical PVC objects based on IR spectroscopy*, Sci Rep, 12 (2022), 1–11.

**[3]** A. Afshari, L. Gunnarsen, P.A. Clausen, V. Hansen, *Emission of phthalates from PVC and other materials*, Indoor Air, 14 (2004), 120–128.

## Notes:

# Partitioning behaviour of diethyl phthalate plasticiser in glass and aluminium surfaces

IAQ Indoor Air Quality in Heritage and Historic Environments
LJUBLJANA, 14 — 16 SEPTEMBER 2022

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A knowledge of the partitioning behaviour of semi-volatile organic compounds (SVOCs), such as phthalates between different materials and their surrounding air is of great importance for quantifying levels of human exposure to these compounds, which have been associated with adverse health effects. Phthalates' partitioning behaviour also represents a key property for modelling and assessing polymer degradation mechanisms associated with plasticiser loss. However, the characterisation of phthalates' partitioning behaviour has been reported only for a limited number of compounds, mainly involving di-2-ethylhexyl phthalate (DEHP), di-isononyl phthalate (DINP) and di-isodecyl phtahalate (DIDP), while the characterisation of diethyl phthalate (DEP) partitioning has been overlooked. As one of the first plasticisers employed in the production of semi-synthetic plastics produced industrially in the late 19$^{th}$ and early 20$^{th}$ century, DEP loss from historic plastic museum artefacts into the air is an important degradation mechanism in historically significant artefacts in museum collections and archives. However, the study of DEP plasticiser loss and its partitioning behaviour in these systems also requires an understanding of how DEP interacts with the surrounding surfaces of the artefact storage enclosure, which at the laboratory scale usually involves aluminium and glass containers. Therefore, here we demonstrate that the partitioning behaviour of DEP between borosilicate glass and aluminum surfaces and their surrounding air can be described by an exponential function of temperature, presenting a model to describe this relationship for the first time [1]. Model parameters are estimated using nonlinear regression from experimental measurements acquired using 109 samples which have been equilibrated at different temperatures between 20 and 80 °C in sealed environments. Quantities of DEP adsorbed on both glass and aluminum surfaces were quantified using UV-Vis spectroscopy in a Shimadzu spectrophotometer 2700, by employing the absorbance intensity of DEP at 226 nm and a seven-point calibration curve. Both glass and aluminum surfaces were washed with an aqueous ethanolic solution (60/40% v/v ethanol/distilled water) and the resultant solutions were analysed. Our results demonstrate that measured partition coefficients have been predicted accurately by our proposed model. The knowledge of DEP equilibrium distribution between adsorptive surfaces and neighbouring environments will be relevant for developing improved mathematical descriptions of degradation mechanisms related to plasticiser loss.

**Keywords: equilibrium distribution, plasticiser loss, plasticiser migration**

**[1]** S. Da Ros, K. Curran, *Modelling and parameter estimation of diethyl phthalate partitioning behaviour on glass and aluminum surfaces,* Chemosphere, 285 (2021), 131414-(1-8).

## Notes:

# Quantification of acids and chromophores in permanent paper upon accelerated ageing

Indoor Air Quality in Heritage and Historic Environments
LJUBLJANA, 14 — 16 SEPTEMBER 2022

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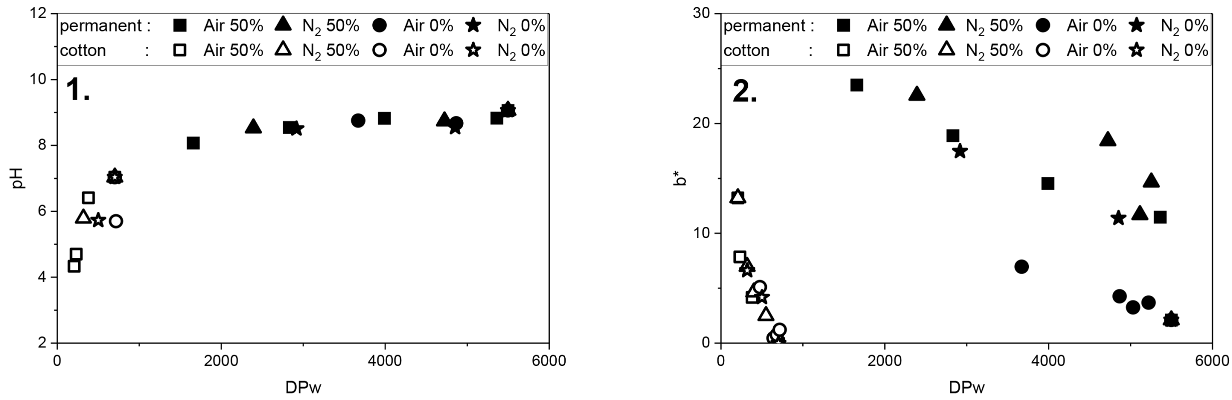
Paper and paperboard are widely used in cultural heritage for the storage of historical objects either as boxes and envelopes, or for the preservation of information as for example labels, notebooks. This material, however, is mainly made of organic fibres and is therefore subject to relatively fast degradation, in the order of a few decades to a few centuries [1]. Moreover, the degradation of paper produces volatile compounds that can catalyse the deterioration of nearby objects [2]. To avoid these phenomena, a standard for a permanent paper grade was developed in the late 1990s. It is based on lignin-free basic pulp and the introduction of an alkaline reserve to prevent acid catalysis of the cellulose hydrolysis. Even if such paper is already used in the conservation field and for the long-term storage of data, the degradation process is still unknown. This study aims at quantifying the degradation of permanent paper.

A bleached kraft permanent paper and an acidic cotton paper were artificially aged under different atmospheres to identify the roles of humidity and oxygen on their chemical degradation. The ageing took place in closed vessels to trap volatile by-products eventually formed (TAPPI T 573 pm-03). This method tends to reproduce the conditions of natural ageing in a stack of paper or a conservation box in a storage room [3]. The degraded states of paper were then characterized using different techniques. Size exclusion chromatography, pH, and colorimetry were used to analyse the production and the consumption of acids and chromophores, some of whom are known to be volatile.

ACIDITY (1) AND YELLOWING (2) OF PERMANENT AND ACIDIC PAPERS AS A FUNCTION OF THE WEIGHT-AVERAGE DEGREE OF POLYMERIZATION DURING AGEING IN DIFFERENT ATMOSPHERES (AIR AND NITROGEN AT 50% AND 0% RELATIVE HUMIDITY).




Not unexpectedly, the degradation rate of permanent paper artificially aged at 90°C was reduced compared to acidic paper. After 25 weeks, the number of cellulose scissions was divided by 25 in air at 50% relative humidity, by 20 in nitrogen at 50% relative humidity, but only by 5 in dry air. Both humidity and oxygen played a role in the degradation, but the mechanisms associated with the permanent paper appeared to be more strongly driven by water.

The production of acids was also reduced compared to acidic cotton paper. This can be explained by the neutralization of acids by the alkaline reserve. However, the acidification was still measurable. Acidity did not depend on the ageing conditions but only on the number of cellulose scissions (figure left). Contrarily, the yellowing was similar in both papers (as measured by b* coordinate in L*a*b* CIE 1976 colour space). The residual lignin present in the bleached woodpulp and not in cotton may be responsible for the yellowing of permanent paper. The production of chromophores depended directly on the ageing conditions (figure right). Oxygen seemed to play a role both on chromophores formation and their degradation. This ongoing study showed encouraging results for the use of permanent paper and the monitoring of its degradation.

**Keywords: cellulose, durability, kinetics, hydrolysis, oxidation**

**[1]** T. H. Horst, R. D. Smith, A. Potthast, M. A. Hubbe, *Accelerated Aging of Deacidified and Untreated Book Paper in 1967 Compared with 52 Years of Natural Aging*, Restaurator. International Journal for the Preservation of Library and Archival Material, 41 (2020), 131–152.

**[2]** J. Tétreault, A.-L. Dupont, P. Bégin, S. Paris, *The impact of volatile compounds released by paper on cellulose degradation in ambient hygrothermal conditions, Polymer Degradation and Stability*, 98 (2013), 1827–1837.

**[3]** P. L. Bégin, E. Kaminska, *Thermal Accelerated Ageing Test Method Development*, Restaurator, 23 (2002), 89–105.

# Emissions of volatile organic acids from lignin and resin acids

IAQ Indoor Air Quality in Heritage and Historic Environments
LJUBLJANA, 14 — 16 SEPTEMBER 2022

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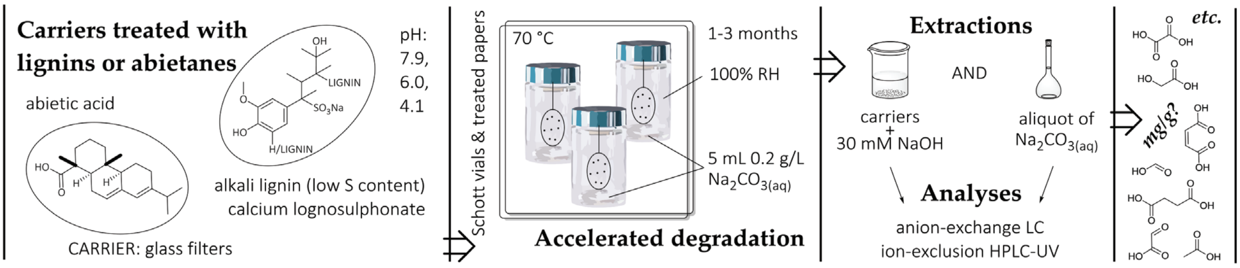
Acidity is the most important factor in historic paper degradation. It is well known that pH of paper can decrease, which is correlated to the formation of acidic degradation products. Low-chain carboxylic acids, especially formic and acetic acid, play a potentially important role due to their low $pK_a$. They are generally assumed to be carbohydrate-derived degradation products. Using capillary zone electrophoresis, Dupont et al. monitored five organic acids in lignocellulosic papers [1]. However, paper is a composite material, meaning that lignin and sizing-derived resin acids might also represent additional source. So, our aim to conduct a systematic study of the sources of organic acids, as well as how, and in what proportions they form, creates a research opportunity, yet also a challenge.

We studied conversion of lignin and rosin-derived abietic acid to organic acids within the pH range 4–8 according to the figure. The studied compounds were applied onto non-cellulosic carriers to reach approx. 150 mg/g of lignin and 5 mg/g of abietic acid. Degradation was performed at 70 °C and 100% humidity in closed vials. During the process, the accumulated volatile acids were captured in 5 mL aqueous $Na_2CO_3$ solution at the bottom of a vial, whereas the non-volatile acids accumulated in the carrier.

The carriers and the $Na_2CO_3$ solutions were periodically analysed during 3 months of accelerated degradation. We monitored lactic, acetic, glyoxylic, propionic, formic, glycolic, pyruvic, succinic, malic, tartaric, maleic, fumaric, and oxalic acid. Their formation was quantitatively determined by anion-exchange chromatography and ion-exclusion HPLC-UV. Dicarboxylates, despite being less mobile, represent a secondary source of volatile monocarboxylic acids, which may altogether increase paper acidity and can cross-contaminate the surrounding artefacts.

The preliminary results point at lignin and abietanes being significant sources of organic acids. Approximately 4.0-, 2.8-, and 2.6-times increases in contents of acetic, formic, and oxalic acid, respectively, were recorded after 1 month of incubation at pH 6. All in all, the experiments are planned to inform our understanding of the sources and the kinetics of accumulation of acidity in historic papers during their natural degradation.

## EXPERIMENTAL SETUP OF THE CONDUCTED ACCELERATED AGING OF TREATED NON-CELLULOSIC CARRIERS




**Keywords: carboxylic acids, historic paper, alkali lignin, lignosulphonate, rosin**

**[1]** A. L. Dupont, C. Egasse, A. Morin, F. Vasseur, *Comprehensive characterisation of cellulose- and lignocellulose-degradation products in aged papers: Capillary zone electrophoresis of low-molar mass organic acids, carbohydrates, and aromatic lignin derivatives,* Carbohydr Polym, 68 (2007), 1–16.

## Notes:

# A quantitative study of the emission rates of acetic acid from the cellulose acetate objects

IAQ Indoor Air Quality in Heritage and Historic Environments
LJUBLJANA, 14 — 16 SEPTEMBER 2022

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Art objects, including plastic artefacts in museum collections, can be major sources of indoor pollution. As these materials degrade, different volatile organic compounds (VOC) are produced and released. A type of so-called malignant plastics, cellulose acetate, is a major emitter of acetic acid, which is produced during its hydrolytic degradation. This acid can cause an increased deterioration of sensitive artefacts which are stored nearby, such as metals and paper. However, VOC emissions from objects are rarely studied and consequently, literature values and suitable experimental methodologies are scarce [1,2].

In this project, sampling of acetic acid emissions from selected plastics at indoor environments was conducted. First, the plastic objects were chemically characterized in terms of their polymer type and plasticizer content, using an ATR-FTIR spectroscopy and GC-FID, after the solvent extraction. The sampling method, which was based on the use of an emission chamber, was developed and validated. The acetic acid emissions from selected objects (3D objects and photographic materials) were collected, using an active sampling mode with the charcoal-based sorbent tubes. Subsequently, the samples were analysed using an ion chromatography method, in order to quantify acetic acid emitted from the objects. In addition to the emission rates, both the mass and the area-specific emission rates of acetic acid were calculated. For some cellulose acetate objects, it was concluded that they exhibit high emission rates of acetic acid, which were in the range between 0.2 and 4.7 µg/h, and could be a source of acetic acid in storage areas. In addition, the surface evaporation and internal diffusion of acetic acid was tested, to see which mechanism is dominant for this type of plastics.

Along with the experimental part, a modelling study was conducted. The calculated acetic acid emission rates were used as the model inputs. The proposed model predicts acetic acid concentrations emitted from individual cellulose acetate objects for various storage scenarios: archival box, display case, and storage room.

**Keywords: cellulose acetate, acetic acid, emission rates, ion chromatography, model**

**[1]** S. H. Smedemark, M. Ryhl-Svendsen, A. Schieweck, *Quantification of Formic Acid and Acetic Acid Emissions from Heritage Collections under Indoor Room Conditions. Part I: Laboratory and Field Measurements,* Herit Sci 8(2020), 58–66.

**[2]** S. H. Smedemark, M. Ryhl-Svendsen, *Indoor Air Pollution in Archives: Temperature Dependent Emission of Formic Acid and Acetic Acid from Paper.* J Pap Conserv, 21(2020), 22–30.

## Notes:

# ▶ Risk theories are a mess

IAQ Indoor Air Quality in Heritage and Historic Environments
LJUBLJANA, 14 — 16 SEPTEMBER 2022

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Currently more than 1,000,000 scientific publications mention the term risk, risk assessment or risk evaluation in a broad variety of domains such as human health, natural disasters or heritage. Despite the importance of risk, several semi-hidden problems limit the use of risk theories such as:

- **Problem of information asymmetry:** The level of risk that an object or subject endures from its surroundings can only be estimated when sufficient information is available about (1) the behaviour of the hazard source and (2) the impact of this source on object or subject. Previous research has shown that the activity of hazards can be highly variable, making it worthwhile to monitor multiple properties of the hazard (e.g., concentration of pollutants that affects air quality) using sensors. Data collected by sensors provides mainly information about the current behaviour of the hazard and much less about the (distant) past. Information about the impact of a hazard is often collected through inspections and gives an insight in the cumulative harm acquired during the past. Continuously measuring actual increases in harm is more complex. The problem with both information sources is that they gather information from different periods. This information asymmetry results in a systematic shortage of information to estimate risk in a reliable way;
- **Conceptual problems:** Risk theories often rely on terms (e.g., risk, uncertainty, value) and principles (e.g., risk = probability × impact) that are either vaguely described or have multiple interpretations. This situation is not uncommon in science because by systematically pushing the boundaries of our knowledge, one necessarily arrives at 'primitive terms' that can no longer be defined and at principles that are so clear that it becomes impossible to find arguments to substantiate them. However, some of the risk-related terms are easier to define by assigning them to the corresponding object, mental image, process, emotion or sensation than describing their meaning with words. Attempts to describe such terms with language sometimes do more harm than good;
- **Problem of scientific objectivity:** Particular perspectives, value judgments, community bias or personal interests influence the way we assess risk or harm. Therefore, it is not possible to attain scientific objectivity in risk theories. However,

the role of the expert building a model to evaluate risk, the agent using that model or the participant processing the risk information is often neglected in these theories;

- **Information visualization problem:** Decision makers have often not the background knowledge in data science or in disciplines that convert observations or measurements into risk. Therefore, they are unable to extract risk-related conclusions from raw information such as graphs showing changes of temperature over time. Such raw information do not inform neither convince them to take action. As a result, essential decisions or actions are delayed and hazards continue to be a threat.

The mentioned problems point to a number of flaws in the risk theories. This contribution wants to delve deeper into these problems and propose some answers. This should allow the development of better quantitative models to estimate risk and improve preventive conservation.

**Keywords:** risk, hazard, risk theory, risk assessment, preventive conservation

## Notes:

# Interactive web applications for the dissemination of heritage science

IAQ Indoor Air Quality in Heritage and Historic Environments
LJUBLJANA, 14 — 16 SEPTEMBER 2022

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The development of various digital applications based on scientific research in the field of heritage science can be a very helpful tool for conservators and curators and, with some modifications, also for the general public. The applications are mostly based on damage functions related to different variables such as relative humidity, storage temperature and other parameters specific to different materials. Utilizing the developed damage function, the degradation of a historical material can be predicted.

By applying the results of the previous studies on the degradation of historical papers [1,2], we have developed an interactive web-based application primarily for users who have no prior knowledge of modelling the degradation of historical objects. The app is available at https://hsll.shinyapps.io/COL_DEM_3/. To improve the usability of the application, the reports can be downloaded with graphical and numerical estimates based on the damage function of the model. We have focused on creating separate tabs to divide the application into logical case scenarios. The Single Object tab focuses on predicting the expected lifetime of a single historical object stored under user-defined conditions. The Collections Demography tab extends the model for a single object to simulate the degradation processes of an entire collection of historical papers. Under user-defined storage conditions, the percentage of usability is calculated and graphically displayed. In this way, the percentage of books classified to be suitable for use and display, as well as the development of the entire collection over time. The Deacidification tab represents an experimental development, simulating the effect of deacidification of randomly acidic historical papers and comparing the degradation of the collection with and without the deacidification process, allowing the user to see the effectiveness of the process.

Each tab provides valuable insight into the degradation processes of historical papers and, most importantly, allows the user to interactively explore how different storage conditions affect the undesirable process of paper degradation. Using this knowledge can lead to easier optimization of storage conditions to ensure that historical paper objects of cultural significance remain usable for many years to come.

A box buffering capacity app was also developed, an open-source application for evaluating the relative humidity buffer capacity (RH) of a box. It can serve as a tool to better understand the behaviour of RH within an enclosure when exposed to various types of external RH fluctuations. It provides a quantitative measure of the buffering capacity of enclosures via Humidity Attenuation (HA) Index, which could aid in future decision making for preventive conservation actions. This application can be used to test the suitability of archival boxes in terms of their ability to buffer external RH fluctuations based on direct measurements of RH fluctuations outside and inside of an enclosure or based on experimental properties of an enclosure, e.g., size, box weight, moisture sorption isotherm, and water vapour transmission rate. The app is available at https://hsll.shinyapps.io/ha_index_pub/.a

**Keywords: web application, R programming language, damage function, heritage science**

**[1]** M. Strlič, C. M. Grossi, C. Dillon et al., *Damage function for historic paper. Part III: Isochrones and demography of collections*, Heritage Science 3 (2015), 40.

**[2]** M. Strlič, C. M. Grossi, C. Dillon et al. *Damage function for historic paper. Part II: Wear and tear*, Heritage Science 3 (2015), 36.

## Notes:

# IoT for sustainability and efficiency in preventive conservation at the Anthropology and Ethnology Museum of Florence

IAQ Indoor Air Quality in Heritage and Historic Environments
LJUBLJANA, 14 — 16 SEPTEMBER 2022

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New technologies are increasingly used to understand the risks to collections of museums and other cultural institutions. In particular, climate monitoring and control strategies to reduce the risks of the interaction between tangible heritage objects and their conservation environments are traditionally based on rigid RH and T values of 50% and 21 °C, but a more flexible object-based approach has been adopted in the recent application of the European Standard EN 15757:2010 [1] and the 2019 review of ASHRAE Applications Handbook [2]. Furthermore, the contribution of the Internet of Things (IoT) to the implementation of tailored, appropriate climate control systems is becoming increasingly significant due to the progress in sensor and data transmission technologies together with the development of cloud computing.

The present work aims to reduce the gap between technological research and museum and conservation practice, by applying an affordable and attractive IoT architecture for cultural institutions. Built on previous research [3], it proposes an integrated collection of climatic data and conservation information, based on historic climate studies according to international standards, and on the conservation needs of hygroscopic materials.

This approach has been used in the study and the care of a museum collection rich in hygroscopic material, the Anthropology and Ethnology Museum in Florence. Four case studies have been chosen and studied from a conservation perspective among the objects preserved in the museum. Moreover, the historic climate in the halls hosting the case studies has been determined based on a monitoring campaign.

The same IoT platform used to collect conservation and climatic data has been used to tailor a climate control system. Real-time remote access to the data was given to the museum staff and conservators, the appropriate alarm logic with immediate feedback to the conservators has been implemented, and active climate control was then introduced and successfully validated.

**Keywords:** IoT, preventive conservation, anthropology museum, ethnographic objects, climate control

**[1]** European Committee for Standardization (CEN), *Conservation of Cultural Heritage—Specifications for Temperature and Relative Humidity to Limit Climate-Induced Mechanical Damage*; Standard EN 15757; CEN: Brussels, Belgium (2010).

**[2]** American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), *Museums, Galleries, Archives, and Libraries. In ASHRAE Handbook: Heating, Ventilating, and Air-Conditioning Applications*; ASHRAE: Atlanta, Georgia (2019).

**[3]** C. Manfriani, G. Gualdani, G. Goli, B. Carlson, A. R. Certo, P. Mazzanti, M. Fioravanti, *The Contribution of IoT to the Implementation of Preventive Conservation According to European standards: The Case Study of the "Cannone" Violin and Its Historical Copy*, Sust, 13 (2021), 1900.

## Notes:

# Balancing air exchange in the face of climate change: Integrating risks from indoor and outdoor-generated pollutants into HVAC energy-saving strategies for heritage institutions

IAQ Indoor Air Quality in Heritage and Historic Environments
LJUBLJANA, 14 — 16 SEPTEMBER 2022

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The Image Permanence Institute (IPI) at Rochester Institute of Technology (RIT), Rochester, NY is currently undertaking a three-year field research project to understand the impact of energy-saving strategies for mechanical system operation on indoor air quality in collection storage spaces. The data collected will help further develop methodologies for strategy implementation, allowing for optimal sustainability while minimizing risks associated with pollutants.

Strategies of temporary system shutdowns, fan speed adjustments, and outside air reduction are proven effective ways to maintain or improve the preservation quality of a collection environment while reducing the financial burden and carbon footprint of a collecting institution. However, current criteria guiding safe implementation of energy-saving strategies focus on temperature and relative humidity alone, which ignores the potential risk to collections posed by pollutants from the reduced air exchanges.

This project addresses these concerns by conducting continuous and passive pollutant monitoring of indoor and outdoor-generated pollutants before and after implementing energy-saving strategies at four partner institutions, representing a range of collection types, but all housed in urban environments on the eastern coast of the United States. Alongside temperature and relative humidity, continuous pollution monitoring includes nitrogen dioxide ($NO_2$), ozone ($O_3$), sulfur dioxide ($SO_2$), total volatile organic compounds (tVOCs), and particulates. Indoor-generated pollutants are periodically monitored by passive samplers (acetic and formic acids) and an additional continuous monitor (formaldehyde). Instrumentation is positioned throughout the mechanical system and collection spaces, and all data is collected to a parts per billion (ppb) level. Additionally, energy monitors have been installed on the mechanical systems serving the collection storage spaces.

In 2022, the focus will be on collecting baseline data across all four seasons and at each institution. During the following year, energy-saving strategies will be implemented across the seasons and compared against the baseline pollutant and energy usage levels. Since harmful pollutants are both indoor and outdoor-generated, it is expected that they will vary in different ways (ex. reducing outside air will cause concentrations of outdoor-generated pollutants to decrease, whereas indoor-generated pollutants will increase without the ability to exhaust or dilute). The primary outcome will be a data collection and modeling procedure to help institutions balance pollutant-level changes while implementing energy-saving strategies based on their specific concerns.

The project team includes collaborations with the Canadian Conservation Institute for expertise in pollutant risks, an independent indoor air quality specialist to assist with analysis, and a mechanical engineer with RIT's Golisano Institute for Sustainability to perform energy usage calculations. While at the time of this conference we will still be collecting baseline data, we welcome an opportunity to share the results up to that point (including instrumentation used, concentrations of pollutants and energy usage during spring and summer seasons, the effects of filtration in removing outdoor-generated pollutants, and observations on standard airflow issues in the collection storage spaces) and receive constructive feedback from attendees.

This project was funded through a grant from the U.S. National Endowment for the Humanities (NEH).

**▶ Keywords: airflow, HVAC, risk assessment, sustainability**

## Notes:

# Museums and smells. How to enhance the impact of cultural heritage collections through olfactory storytelling



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This lecture provides an introduction to the role of smell in heritage institutes. Over the last decades, museums and other heritage institutes have become more interested in experimenting with multi-sensory strategies, to engage their audiences. Visitors are invited to touch heritage objects, to listen to soundscapes in museums, and also to make use of their noses while engaging with works of art. In recent years olfactory displays and storytelling have gained momentum in heritage institutes, altering the traditional ideal of the museum as an ‚anosmic cube'. In this lecture, it will be discussed how the Odeuropa research project is developing new tools, strategies and research for museums to enhance their impact through olfactory storytelling.

**Keywords:** smell, sensory strategies, olfactory, Odeuropa

# Notes:

Indoor Air Quality in Heritage and Historic Environments
LJUBLJANA, 14 — 16 SEPTEMBER 2022

# New VOCs in the museum: balancing impact and value

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After decades of engaging with heritage primarily through our eyes, museums are discovering the value of a multisensory approach to collection curation and interpretation. As a result, many galleries, libraries, archives and museums (GLAMs) introduce olfactory components as part of the displays or as part of public engagement initiatives. While smells can enhance collection discovery and visitor experience [1,2], the impact of newly introduced VOCs on collections and IAQ has, until now, not been systematically researched. Working within the frame of the Horizon 2020 project Odeuropa [3], we've identified a series of conservation and interpretation issues related to working with smell in museums, which research in the emerging field of olfactory heritage seeks to address. In this paper, we will discuss some of the concerns of heritage professionals around challenges posed by the introduction of scents in the gallery space, with notes towards developing best practice.

**[1]** C. Spence, *Scenting the Anosmic Cube: On the Use of Ambient Scent in the Context of the Art Gallery or Museum*, I-Perception 11 (6) (2020).

**[2]** J. P. Aggleton, L. Waskett, *The Ability of Odours to Serve as State-Dependent Cues for Real-World Memories: Can Viking Smells Aid the Recall of Viking Experiences?* British Journal of Psychology 90 (1) (1999), 1–7.

**[3]** https://cordis.europa.eu/project/id/101004469.

## Notes:

# Olfactory exhibitions in museum environments. Developing a risk assessment methodology

IAQ Indoor Air Quality in Heritage and Historic Environments
LJUBLJANA, 14 — 16 SEPTEMBER 2022

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In the recent years, interest in the sense of smell has increased greatly in the museum community, initiating diverse projects exploring odour exhibition and conservation. [1]

Olfactory exhibitions are increasingly of interest to cultural heritage institutions, where smells are exhibited as part of museum collections. The value of olfactory exhibits often lies in the enhancement of physical objects by adding another sensory dimension. Smells can be displayed in addition to physical objects, but can be works of art themselves, engaging visitors through associations with personal experiences as well as by enhancing new experiences [1].

Odours used in olfactory exhibitions consist of volatile organic compounds (VOCs), i.e. substances with a high vapour pressure at room temperature [2]. Due to their volatility and reactivity they can represent a conservation risk for the surrounding objects or can affect human health, as some could be harmful, irritating or cause allergic reactions. VOCs could induce hydrolysis or oxidation of materials, causing the formation of new degradation products [3]. Although the effects of VOCs on heritage materials have been studied, little is known about the risks represented by some of the frequently used odoriferous compounds or their mixtures. To investigate this, we adapted the Oddy test by directly injecting the VOCs of interest, or their mixtures, into the Oddy test flasks. This allowed us to evaluate the effect of VOCs on metals, these being particularly sensitive to environmentally induced degradation. The setup involved different compounds and concentrations and allowed us to determine whether or not the VOCs used during olfactory exhibitions may pose a risk to the surrounding collection at what could be considered realistic concentrations.

**Keywords: volatile organic compounds, olfactory exhibition, Oddy test**

**[1]** C. Bembibre Jacobo, *Smell of Heritage*, PhD thesis, UCL (2020).

**[2]** A. Alvarez-Martin, M. Wilcop, R. Anderson, D. Wendt, R. Barden, G. M. Kavich, *Investigation of volatile organic compounds in museum storage areas*, Air Qual. Atmos. Heal., 14(11) (2021), 1797–1809.

**[3]** C. M. Grzywacz, *Monitoring for Gaseous Pollutants in Museum Environments*, Getty Publications (2006).

# Notes:

# Whether the stench of mould could be a part of cultural heritage

IAQ Indoor Air Quality in Heritage and Historic Environments
LJUBLJANA, 14 — 16 SEPTEMBER 2022

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Heritage places with none or very limited regulation of microclimate conditions are at the risk of moulds growth both on structural elements of buildings and on the historical objects stored inside them [1]. In Poland usually, this is the problem in small local museums with very limited budgets, which can't afford to install and run sophisticated ventilation systems, which would allow to keep a stable temperature and relative humidity. This is also a really serious problem in old, historical Polish churches, which often have no central heating system installed. In these cases, the temperature and relative humidity outside the building directly influence the microclimatic conditions inside. During longer summer raining periods or at the end of spring/beginning of autumn the relative humidity in the mentioned buildings can reach very high levels, favouring the growth of moulds. Moulds growing on the walls and other structural elements, as well as on objects, emit so called Microbial Volatile Organic Compounds (MVOCs) which are the ingredients of the very specific smell of moulds [2].

The persistent growth of moulds in historical buildings and churches leads to the place being filled with the smell of moulds (MVOCs). Sometimes, even after professionally removing the moulds from the walls or ceilings, the smell of fungi is still present, as the MVOCs are now emitted from the furniture and other elements of building equipment which were filled with the moulds smell. Thus, it can be concluded that the "stink" of moulds is now part of the historical heritage of old buildings and churches.

The main goal of the investigation was the gas chromatography–mass spectrometry (GC-MS) analysis of MVOCs emitted by moulds growing in the storage room of an old church in Cracow. The room has no heating system, the old windows are single pane and not airtight, meaning that the microclimate of the place is directly influenced by weather. Thus, in the "wet" period of the year this creates favourable conditions for high relative humidity and for moulds growth. After qualitative and quantitative analysis of MVOCs present in the investigated room, the smell of the place was defined. In the next step this smell was recreated by mixing the main chemical compounds found in GC-MS chromatograms. The recreated smell was subjected to olfactometric tests. The panel of experts defined the name of the smell, assessed its hedonic quality and its acceptance.

**Keywords:** MVOCs, moulds smell, GC-MS, olfactometry

**[1]** T. Sawoszczuk, J. Syguła - Cholewińska, J. M. del Hoyo – Melendez, *Optimization of headspace solid phase microextraction for the analysis of microbial volatile organic compounds emitted by fungi: Application to historical objects,* Journal of Chromatography A, 1409 (2015), 30–45.

**[2]** T. Sawoszczuk, J. Syguła - Cholewińska, *Application of solid phase microextraction–gas chromatography–mass spectrometry method for the detection of active moulds on historical objects,* Heritage Science, 5(20) (2017).

## Notes:

# How to investigate smellscapes in heritage places using smellwalks and smell diaries

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Indoor air quality is also a matter of perception. It can be evaluated both by quantitative and qualitative measures. An interesting focus on qualitative perception of indoor air quality is the olfactory environment. Indeed, the smells of a place often carries along identity, emotions, representation, attachment… A "smellscape" is a term first coined by geographer J. Douglas Porteous in 1985 [1] and defines the olfactory environment as it is perceived by a person in a certain place at a certain time.

Within the H2020 funded project Odeuropa, I am doing a PhD research on smellscapes in GLAMs and heritage sites. One of the main objectives of this research is to help recognize smell as an important factor in the process of "making sense of a place" and in determining the identity of this place.

Researching smellscapes can give an insight about how people perceive and engage with a certain place. Their relationship with the place is influenced by the sensorial stimuli experienced there. They, in turn, can influence this smellscape by their activities in the place. Smellscapes are therefore an insightful perspective on indoor air quality as perceived and influenced by the people who spend time and engage in a certain place.

A smellscape is context-dependent. My methodology to research smellscapes in GLAMs and heritage sites is diverse and draws from primary research, semi-structured interviews, on-site qualitative investigation and chemical analysis. In this presentation, I will succinctly present the methods I use for the primary research, interviews and the chemical analysis, to mainly focus on the on-site qualitative investigation, namely the smellwalk [2] and the smell diary methods.

This sensory method of investigation focuses on a nose-first approach and an embodied experience of a place. The type of data I collect from smellwalks and smell diaries are essentially words. The question of translating olfactory stimuli into a communicable language is also challenging: I will present how smellwalk and smell diaries can help foster comments and words to translate one's sensorial impressions.

I will end the presentation with considerations about the heritage importance of smellscapes. The few recent smell preservation projects such as the "100 most fragrant spots" in Japan, the UNESCO classification of the Grasse region, the French law to protect country's sounds and smells, the Odeuropa project… show there is a shift in the field of cultural preservation [3]. It is therefore insightful to research how such elusive yet powerful olfactory-scape shape our perception of air quality and how they can be part of our cultural heritage.

**Keywords: smellscapes, smellwalks, sensory methodology, olfactory heritage**

**[1]** J. D. Porteous, *Smellscape, in Landscapes of the mind, worlds of sense and metaphor*, University of Toronto Press (1990), 21–45.

**[2]** V. Henshaw, K. McLean, D. Medway, C. Perkins, G. Warnaby, *Designing with Smell: Practices, Techniques and Challenges* (1st ed.). Routledge (2017), 67–77.

**[3]** A. Jasper, J. Otero-Pailos, *Smell and preservation*, Future Anterior, 13 (2) (2016), 3–7.

## Notes:

# POSTERS

# Effect of volatile organic compounds in indoor air on the stability of ultramarine blue paints

IAQ Indoor Air Quality in Heritage and Historic Environments
LJUBLJANA, 14 — 16 SEPTEMBER 2022

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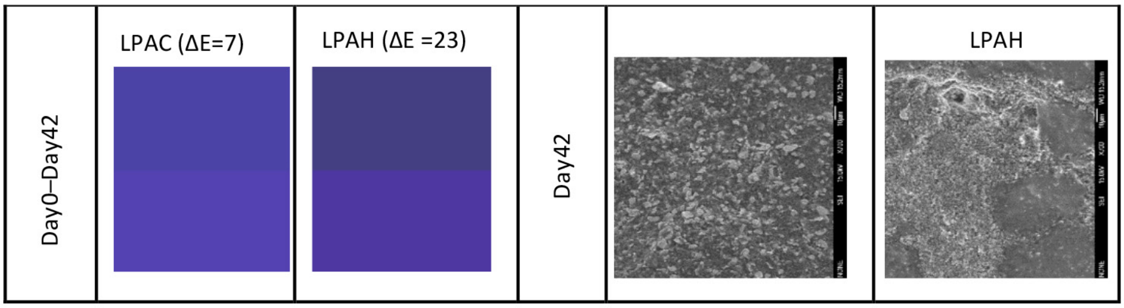
Synthetic ultramarine blue is a sodium aluminosilicate used by several painters since 1824. Supposedly stable, its primary degradation is cited in the literature as "ultramarine disease" and refers to the fading of the colour to a greyish tone. The cause of this modification is not yet fully known. The sensitivity of the pigment to acids or changes in the binder induced by environmental factors could be the causes. However, few studies verify the possibility of chemical pollutants causing some effect on pigments. The objective of this work was to verify the behaviour of oil-painted ultramarine blue under the influence of Volatile Organic Compounds (VOCs). Painting models were prepared on cotton canvas using ultramarine blue and linseed oil and primed with lead white or plaster, as this is a standard canvas preparation procedure. The samples were exposed inside test chambers containing the following VOCs (acetic acid, hexanal, 2-butanone oxime and formaldehyde). These compounds were chosen because they were found in museum atmospheres, in previous works by the research group [1]. A control was also reproduced, with no VOCs. After 42 days of exposure, the following analyses were performed on the surface of the paintings: colour ($\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$), scanning electron microscopy (SEM) and Attenuated Total Reflectance Infrared (FTIR-ATR). Significant changes occurred in samples with white lead primer, where the FTIR-ATR spectra showed signs related to the formation of lead acetate, formate and hexanoate. In the images of these models (figure), the granular appearance was replaced by regions with a smooth and homogeneous appearance, where the corresponding carboxylate was deposited. The formation of some cracks was understood as places where the surface of the original painting remained. There were also significant colour changes in these samples (figure) ($\Delta E$ minimum 2x the control value), including all models exposed to 2-butanone oxime. There was an increase in parameter b (towards yellow) and a decrease in parameter a (towards green). The increase in $\Delta E$ led to a decrease in chroma. The colour in the model became less intense than in the original, while the luminosity did not change significantly. This work shows the impact of air quality on the components of a painting and understanding the risks associated with exposure to indoor air pollution.

**CHANGING OF COLOUR FOR ULTRAMARINE PICTORIAL MODELS. L- CANVAS; P-LEAD; A-ULTRAMARINE; C-CONTROL, H-HEXANAL. SEM MICROGRAPHS OF THE PAINT SURFACE.**




**Keywords: VOCs, museum, pigment, indoor air quality, colour**

**[1]** B. Sánchez et al., *Volatile organic compounds in the Spanish National Archaeological Museum: Four years of chemometric analysis,* Building Environment, 174 (2020), 1–9.

## Notes:

# Exposure assessment of toxic metals and organochlorine pesticides among 28 employees of a natural history museum

IAQ Indoor Air Quality in Heritage and Historic Environments
LJUBLJANA, 14 — 16 SEPTEMBER 2022

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Chemicals such as arsenic (As), mercury (Hg) and organochlorine biocides (OCB) have been extensively used as preventive and curative conservation treatments for cultural and biological collections to protect them from pest and mould infestations. Most of the aforementioned compounds have been classified as carcinogenic, mutagenic and teratogenic and represent a health risk for staff exposed to contaminated objects. Due to the parallel use of As, Hg and OCB, a mixture of these substances can be found on the objects. Although there is a non-specific awareness regarding potential health hazards, a great deal of uncertainty among employees working with contaminated objects remains. Therefore, the external and internal exposure to biocides of employees working at the Museum für Naturkunde Berlin (MfN) was investigated. This study was funded by the German Federal Foundation for the Environment (DBU) and took place from December 2016 to December 2018.

For the evaluation of the external exposure, As, Hg and OCB (e.g. DDT, lindane, PCP and their metabolites) were analyzed in air and dust samples at 15 different locations. Additionally, fine particles were also monitored. For interal exposure, blood (OCB) and urine (As, Hg) samples were collected from 28 employees. Furthermore, the employees were asked to answer a questionaire about work-related activities to understand possible exposure pathways and to identify health risks.

Based on the ambient monitoring, it was shown that objects at the MfN can be a cause of an exposure to hazardous substances when working with the objects [1]. The results also confirmed the extensive use of arsenic, mercury and lindane as preservatives. In the accompanying human biomonitoring the employees, no exceedances of toxicologically relevant biological assessment or limit values were found [2]. However, relatively high concentrations of inorganic arsenic, especially of the species As(V), were found in the urine of the employees compared to the general population. In addition, various work-related factors, such as not using gloves and high dust formation during work, correlated significantly with the concentration of arsenic, mercury and selected organochlorine pesticides in urine or blood, respectively. Based on the study, a guideline was written to assist decision-makers and employees in handling contaminated objects [3]. The guideline includes chapters on hazardous substances, exposure routes, risk assessment, the legal situation and occupational medicine.

Considering the potential health risks from exposure to these chemicals and the lack of knowledge of possible synergistic effects, occupational health and safety measures should be implemented in every museum, historical library and herbarium in order to protect the employees from potential adverse health effects.

**Keywords: arsenic, mercury, museum collections, occupational exposure, organochlorine pesticides**

**[1]** K. Deering, E. Spiegel, C. Quaisser, D. Nowak, R. Schierl, S. Bose-O'Reilly, M. Garí, *Monitoring of arsenic, mercury and organic pesticides in particulate matter, ambient air and settled dust in natural history collections taking the example of the Museum für Naturkunde, Berlin*, Environ Monit Assess. 191(6) (2019), 375.

**[2]** K. Deering, E. Spiegel, C. Quaisser, D. Nowak, S. Rakete, M. Garí, S. Bose-O`Reilly, *Exposure assessment of toxic metals and organochlorine pesticides among employees of a Natural History Museum*, Environ Res. 184 (2020), 109271.

**[3]** E. Spiegel, K. Deering, C. Quaisser, S. Böhm, D. Nowak, R. Schierl, S. Bose-OReilly, *Handreichung zum Umgang mit kontaminiertem Sammlungsgut [Guidance on dealing with contaminated collection items]. Handbuch der betriebsärztlichen Praxis*, 74 (2019).

# Notes:

# Innovative (multi-)methods for the safe handling of biocide contaminated objects – The MUSA-project

IAQ Indoor Air Quality in Heritage and Historic Environments
LJUBLJANA, 14 — 16 SEPTEMBER 2022

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Numerous collection objects are contaminated with toxic substances as a result of previous treatments to prevent pest-related decay. According to a non-representative study, 80% of the employees in museums in Germany, Austria, and Switzerland suspect contaminated objects in the depots and exhibitions [1]. These objects are often no longer exhibited or restored in fear of a harmful exposure and are consequently withdrawn from exhibition and loan. We could show that these damaging old restorations pose a potential health hazard to employees and visitors due to the hazardous materials used, and complicate or impair the accessibility and thus the preservation and mediation of cultural property [2,3].

In order to assess the risk of hazardous substances and thus ensure adequate protection of staff and visitors, comprehensive and regular environmental monitoring should be carried out. This can also facilitate the preservation and communication of cultural assets. However, systematic analyses or large-scale studies can hardly be carried out using established analytical methods, as they are usually very time-consuming and therefore cost-intensive.

To overcome this unsatisfactory situation, our goal is the simplification of environmental monitoring in institutions with contaminated objects. The presented study titled "MUSA - Innovative (multi-)methods for safe handling of hazardous restorations" is funded by the Deutsche Bundesstiftung Umwelt (DBU) and will start in June 2022. The objective of this project is a data-based assessment of the hazard potential by a simplified monitoring programme in institutions with potentially contaminated objects. The field phase will be conducted in collaboration with selected museum partners and collections in Bavaria, Germany.

In detail, during the three-year project, we aim to develop innovative (multi)-methods for environmental monitoring in collections contaminated with hazardous substances to enable comprehensive and cost-effective hazard detection and assessment due to damaging old restorations. Based on our previous projects, the selection of biocides for method development will focus on arsenic and mercury, but also lead and chromium as representatives of the toxic metals, as well as PCP, lindane, DDT and DDE as representatives of the organochlorine pesticides (OCP) [2,3]. In addition, an innovative, cross-institutional "traffic light" system (benchmarking) will be used as an incentive to reduce biocide exposure and consequently the health risk of employees. Therefore, the sample sizes required to evaluate hazard potentials and perform meaningful statistical analysis will be realized. An IT system in the form of a web-based solution will be developed for easy evaluation of the data, providing users with direct access and visualization of the information.

**MUSA** - Innovative (Multi-)Methoden zum sicheren Umgang mit Schädigenden Altrestaurierungen - Entwicklung kostengünstiger, innovativer (Multi-)Methoden für das Umgebungsmonitoring in biozidbelasteten Museen, Denkmälern, Sammlungen und Archiven zum sicheren Umgang mit (gesundheits) schädigenden Altrestaurierungen.

**Keywords: organochlorine pesticides, toxic metals, museum collections, occupational exposure, occupational health and safety**

**[1]** K. Deering, *Die Analyse chlororganischer Pestizide in der restauratorischen Praxis - Bedarfserfassung, Definition eines Prozessplanes und Evaluation der Gaschromatografie-Ionenmobilitätsspektrometrie als analytische Methode.* Hochschule der Künste Bern: Bern. (2015), 167.

**[2]** K. Deering, E. Spiegel, C. Quaisser, D. Nowak, S. Rakete, M. Garí, S. Bose-O`Reilly, *Exposure assessment to heavy metals and organochlorine pesticides among staff members of a Natural History Museum*, Environ Res. 184 (2020), 109271.

**[3]** K. Deering, E. Spiegel, C. Quaisser, D. Nowak, R. Schierl, S. Bose-O'Reilly, M. Garí, *Monitoring of arsenic, mercury and organic pesticides in particulate matter, ambient air and settled dust in natural history collections taking the example of the Museum für Naturkunde, Berlin*, Environ Monit Assess. 191(6) (2019), 375.

## Notes:

Indoor Air Quality in Heritage and Historic Environments
LJUBLJANA, 14 — 16 SEPTEMBER 2022

# Assessment of air quality by diffusive sampling at the Museum of Art and Science

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As is well known, indoor air quality can influence the conservation of works of art exhibited inside museums.

The purpose of this work was to define the environmental conditions in which the museum collections are exhibited to highlight the potential danger to the objects contained in it.

A monitoring campaign was carried out in the Museum of Art and Science located in the city centre of Milan. This museum is hosted in a residential building located near a traffic road. It contains a collection of paintings, wooden objects, ancient ceramics and ivories, tapestries and statues and an important collection of Buddhist art.

The evaluation of the indoor air quality was performed inside three rooms, each one containing different materials and in one display case inside one of the rooms.

The rooms have been selected based on the content: MR (containing African Mask), TR (containing tapestries) and LR (owner's office with ancient paintings and scientific devices)

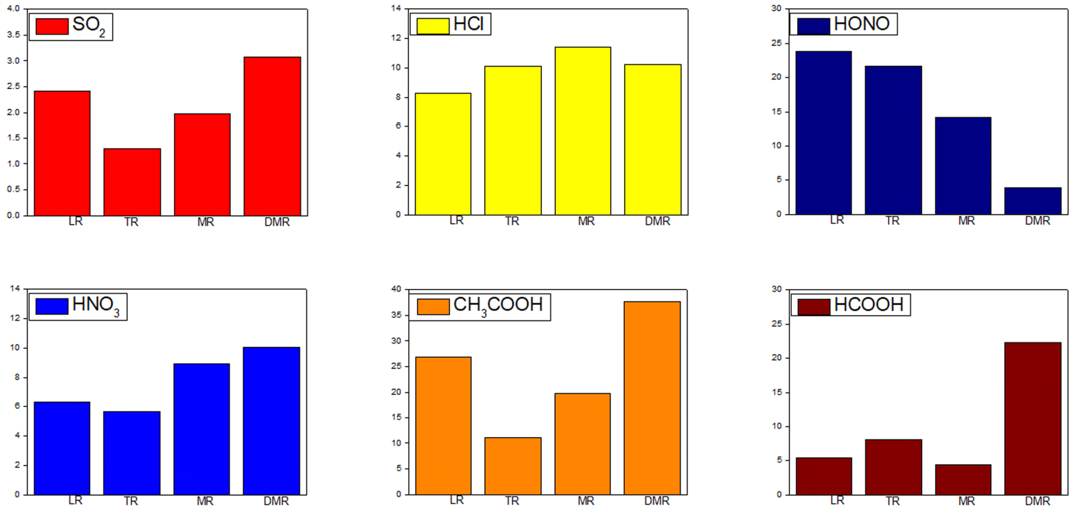
The display case is in the Masks Room and contains wooden African figures (DMR).

The rooms are arranged on two floors, LR in mezzanine floor with window and air conditioner while the others in a basement with air extractor and small windows.

Monitoring was performed by diffusive samplers (Analyst™) for determination of inorganic species $SO_2$, HCl, HONO, $HNO_3$ and two volatile organic compounds (VOCs), HCOOH and $CH_3COOH$.

The results of the measurements are reported in the figure.

## AVERAGE CONCENTRATION OF $SO_2$, HCL, HONO, $HNO_3$, HCOOH AND $CH_3COOH$ MEASURED IN THE THREE SELECTED ROOMS AND IN DISPLAY CASE




The $SO_2$ level was quite low in all environments (average 1.9 µg/m$^3$).

$HNO_3$ with an average concentration of 7.7 µg/m$^3$ shows the maximum value in display case where HONO, with an average concentration of 16 µg/m$^3$, shows the minimum value (3.8 µg/m$^3$).

$HNO_3$ and HONO come from nitrogen oxides through complex reaction pathways. $HNO_3$ is a very aggressive acid in contrast with HONO. The latter is not particularly active by itself, even if it is an important source of OH radicals, one of the most important air oxidants which leads to the formation of various species of oxidative and/or corrosive nature, including inorganic and organic acids [1].

$CH_3COOH$ with an average concentration of 10 µg/m$^3$ shows the minimum value in room containing tapestries and maximum value inside display case (38 µg/m$^3$), as well as formic acid (22.3 µg/m$^3$).

Acetic acid and formic acid are emitted by a lot of material like construction and building materials, wood, coatings, sealants, paints and adhesives and they are also an oxidative product of formaldehyde [2].

The gaseous pollutants concentrations in this museum are relatively homogeneous, with little correlation between the materials in the rooms and the pollutants measured. High concentrations of all gaseous pollutants, except for HONO, were found in the display case, particularly for HCOOH and $CH_3COOH$. The lower level of HONO may be related to its photodissociation and the formation of organic acids.

▶ **Keywords: air quality indoor, passive sampler, gaseous pollutants, display case**

**[1]** S. Gligorovski, *Nitrous acid (HONO): An emerging indoor pollutant,* Journal of Photochemistry and Photobiology A: Chemistry 314 (2016), 1–5.

**[2]** M. R. Raychaudhuri, P. Brimblecombe, *Formaldehyde oxidation and lead corrosion,* Studies in Conservation 45.4 (2000), 226–232.

# Selection of wood for museums based on its trends in chemical emission

Indoor Air Quality in Heritage and Historic Environments
LJUBLJANA, 14 — 16 SEPTEMBER 2022

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Although the emission of acetic acid and formic acid from wood materials in museums is a common issue, the use of wood is expected to continue for the foreseeable future because there is no well-established alternative material. To safely store museum artifacts, wood should contain chemical substances that give off few emissions; however, the amount of emissions and their temporal variations vary among the types of wood, which complicates the selection.

Emissions of chemicals from construction materials, including wood, can be classified into two phases: the first decay phase, during which a large amount of chemical substances are emitted short-term, and the second decay phase, during which a small amount of chemicals are emitted over time. It is well established that a double exponential function model fits well with the two-phase emission behavior of VOC from construction materials [1]. If this model is applied to the emission behavior of organic acids from wood, relative comparisons of emissions from each material become possible. The author has confirmed that this model applies to plywood and thin wood board [2]. The double exponential function model was applied to the emission behavior of acetic acid and formic acid from natural wood in the present study. Furthermore, the amount of emissions was compared using the total emission [3], which is determined through numerical analysis.

Paulownia (*Paulownia tomentosa*), Japanese cedar (*Cryptomeria japonica*), Japanese oak (*Quercus* sp.), and Japanese cypress (*Chamaecyparis obtusa*) were used as test samples because they are frequently used for storage boxes and rooms. A small chamber was used to conduct emission tests over a period of 34 or 35 days at a predetermined interval. The least squares method was used to fit the double exponential function model to the acetic acid emission rate of the test sample obtained during the test. Results showed that the regression curve fits well with the actual measured values, and the amount of acetic acid emitted in each phase was determined. Approximately, 95% of the total acetic acid emission was emitted during the second decay phase. Thus, the acetic acid emission from each wood can be compared relatively by comparing the acetic acid emission during the second decay phase. The model's application allows for the predicted emission rates, which in turn enables the calculation of spatial concentration. Comparing the test samples indicated that acetic acid emission was greatest in paulownia, followed by Japanese oak during the second decay phase. Future studies by collecting data on each wood type and analyzing the trends will aid in the selection of wood for museums.

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**Keywords: wood material, organic acids, emission, selection, double exponential function**

**[1]** J. C. S. Chang, Z. Guo, *Characterization of Organic Emissions from a Wood Finishing Product –Wood Stain*. Indoor Air. 2(3) (1992), 146–153.

**[2]** T. Kotajima, *Studies on Acetic Acid Emission from Plywood Used in Display Cases for Museums*, doctoral dissertation, Tokyo University of the Arts, (2017).

**[3]** G. Iwashita, *Pilot Study on the Method for Modelling the Time Series Emission Rate of Voratile Organic Compounds Emitted from Polyurethane*, Journal of Architecture and Planning (Transactions of AIJ), 64, 522 (1999), 61–66.

## Notes:

IAQ Indoor Air Quality in Heritage and Historic Environments
LJUBLJANA, 14 — 16 SEPTEMBER 2022

# Detection and quantification of the emission of formic acid and acetic acid under in-situ storage and display environmental conditions in museum

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Airborne pollutants are invisible and accumulative inside museum environment. Some of them are acidic in nature and pose a significant risk to the integrity of artefacts. Acetic acid and formic acid are considered one of the corrosive volatile organic compounds (VOC) which are the emission of fabrication works or furniture products. Several methods are available for the analysis of acetic acid and formic acid, involving both active and passive sampling, and instrumental analysis with HPLC-PAD, GC-FID, GC-MS and IC which achieve different detection limit in various ppb level.

Museum guidelines for collection storage environment published by recognised organisations such as Getty Museum and ASHRAE demand very low concentration of airborne pollutants in part-per-billion (ppb) level [1]. Most of the airborne pollutants are detectable by instant and portable devices, while limit of detection (LoD) of such devices which meet targets for museum use are commercially accessible. Only the analysis of acetic acid and formic acid requires hand-on sample preparation followed by instrumental analysis with ion chromatography-conductive detector (IC-CD). It is also proven to achieve a low detection limit in sub-ppb level that can meet our operational needs.

This poster includes progressive method development and validation on the sample preparation and application of IC-CD to analyse the concentration of acetic acid and formic acid, necessary statistics also evaluate the feasibility of the modified analytical method. Hands-on procedures of IC-CD suggested by previous studies revealed different restrictions or dilemma, such as requirement of relatively long analysis time and intensive training to prevent cloggage of expensive IC column. Modification of an existing analytical method [2] that reduces the chance of column cloggage by switching to IC column with lower internal pressure and the mobile phase, followed by simple matrix dilution to tackle matrix interference caused by TEA with NaOH used as mobile phase, while the low LoD of acetic acid and formic acid recommended by Getty Museum (5 ppb for sensitive materials [1]) could still be achieved. Findings of the acetic acid and formic acid content sampled from different furniture in museum collection stores would also be revealed in the poster.

**Keywords: artefact preservation, airborne pollutants, organic acids, passive sampling, preventive conservation**

**[1]** C. M. Grzywacz, *Monitoring for gaseous pollutants in museum environments*, Getty Conservation Institute (2006).

**[2]** M. Stranger, S. Potgieter-Vermaak, P. Sacco, F. Quaglio, D. Pagani, C. Cocheo et al., *Analysis of indoor gaseous formic and acetic acid, using radial diffusive samplers,* Environ Monit Assess. 149(1) (2009), 411–7.

## Notes:

IAQ Indoor Air Quality in Heritage and Historic Environments
LJUBLJANA, 14 — 16 SEPTEMBER 2022

# Field studies of new adsorbents for the capture of pollutants in cultural heritage environments

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Cultural heritage collections in confined, low-air exchange spaces such as display cases and storage containers can present air quality issues, particularly if construction materials or collection objects within the space off-gas corrosive compounds. Adsorbents such as activated carbon are often used to reduce such pollutants and minimize their effects on collections. However, many common commercial adsorbents capture pollutants with weak physical (e.g. van der Waals) bonds, which could lead to re-release of the captured pollutants back into their environment. Within the framework of the EU APACHE project (Active & intelligent PAckaging materials and display cases as a tool for preventive conservation of Cultural Heritage), new adsorbent materials have been developed that form strong chemical bonds between the adsorbent surface and pollutants such as acetic acid, formic acid, acetaldehyde, formaldehyde, and nitrogen dioxide. These adsorbents have been integrated into foam sheets made of affordable materials that are easily deployed in storage and display spaces. The performance and capacity of the adsorbents were previously assessed in controlled laboratory tests, but it is also necessary to ensure that adsorbents perform well under complex, real-life conditions. This study presents the results from three field studies in which the adsorbent foam was placed in a display case and storage containers at the Vasa Museum and the National Archives of Sweden.

At the Vasa Museum, the first and second field studies involved placing adsorbent foam sheets inside a display case (3.4 $m^3$) and plastic storage containers (0.0225 $m^3$), respectively, both containing archaeological wood. At the National Archives of Sweden, the third field study involved integrating adsorbent sheets into lidded archival cardboard boxes (0.006 $m^3$) containing cellulose acetate photographic

negatives. In all studies, passive air quality samplers were used to quantify pollutant concentrations before and after adding the adsorbent foam sheets. Results showed that the adsorbent reduced pollutant concentrations inside smaller spaces like the storage containers, but had little effect in the display case, which was much larger in volume. Additionally, the archival cardboard boxes also adsorbed pollutants, indicating that a combination of adsorbent foam and archival boxes are beneficial for collection protection.

**Keywords: adsorbents, pollutants, storage, display, passive sampling**

## Notes:

# Preventive conservation of display objects: improvements in testing case materials emissions

IAQ Indoor Air Quality in Heritage and Historic Environments
LJUBLJANA, 14 — 16 SEPTEMBER 2022

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Museum display cases are designed not only to expose, but also to preserve the precious objects inside them. However, their closed and confined environment could cause an increase in the concentration of volatile compounds (VC) emitted by the artifact and/or by the case itself, producing a completely opposite effect [1]. For this reason, it is important to check the emission of raw materials employed for the display cases. This is commonly performed through the Oddy test or the BEMMA scheme - an emission chamber test performed by the German Federal Institute BAM [2]. However, the information obtained by these two tests does not provide a complete evaluation of the risk which potentially comes from the interaction between the emitted chemicals and the exposed object.

The aim of this project is to improve the knowledge on this common problem with two different strategies: i) by obtaining quantitative VC analysis results with a new emission chamber-based test; and ii) by analysing the composition of the corrosion products of the Oddy test metal coupons.

For the emission chamber test, we will project a chamber specifically aimed to evaluate the emission of volatile compounds from materials through time and at different temperatures, in order to obtain a more reliable estimation of the total amount of volatile compounds emitted in the materials lifetime. The combination of quantitative and qualitative information will be a first step towards the ideal goal of setting reliable and not a priori limits of concentration for gaseous compounds inside display cases.

For the Oddy test, we will characterize the metal coupons of test-failed materials, mainly with non- or micro-invasive IR spectroscopy techniques, highlighting the potential of this kind of analysis as an implementation of the simple visual check of the induced modifications, which is, nowadays, the usual control method.

**Keywords: volatile compounds, display cases, preventive conservation**

**[1]** O. Chiantore, T. Poli, *Indoor Air Quality in Museum Display Cases: Volatile Emissions, Materials Contributions, Impacts,* Atmosphere, 12.3 (2021), 364.

**[2]** E. Canosa, A. Wiman, S. Norrehed, M. Hacke, *Characterization of Emissions from Display Case Materials* Riksantikvarieämbetet, (2019), 67.

## Notes:

# Air quality in the prefabricated temporary storage for the rescued cultural properties

IAQ Indoor Air Quality in Heritage and Historic Environments
LJUBLJANA, 14 — 16 SEPTEMBER 2022

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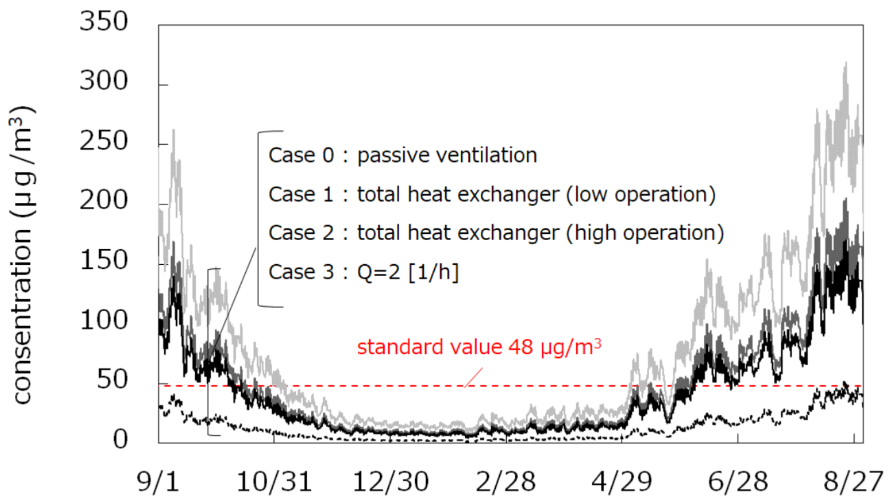
The construction of prefabricated storage is one of the options for temporary storage of the rescued cultural properties from the damaged museum by disasters, along with the use of closed schools and vacant rooms in existing cultural facilities. The long-term measurement of air quality, temperature and humidity were carried out to construct a favourable conservation environment in a highly airtight prefabricated storage constructed for the rescued cultural properties in the Great East Japan Earthquake in 2011.

The air concentration of acetaldehyde exceeds Japanese health guidelines (48 µg/m$^3$) even 7 years after the construction. Monthly measurements of air quality and temperature showed high seasonal change and high correlation between the acetaldehyde concentration and temperature. The apparent volumetric emission rate considering temperature dependence was identified from the measured values of acetaldehyde concentrations and temperature, and the prediction of annual change of acetaldehyde concentrations was conducted to estimate the effects of ventilation. The figure shows the calculated results of annual change of acetaldehyde concentrations with different ventilation methods. The calculated results show that the acetaldehyde concentrations exceed the guideline values from May to mid-November only with passive ventilation, indicating that active ventilation is necessary during this period. It is also found that the operation of the total heat exchanger installed in the storage can reduce the airborne concentration by half compared to passive ventilation alone, but the air change rate needs to be increased to 2 [1/h] to keep it below the standard value throughout the year. Though forced introduction of outdoor air by a blower is necessary to achieve air change rate of 2 [1/h], the numerical analysis shows that the acetaldehyde concentration recovers to the same values as without forced ventilation in less than half a day after the total heat exchanger was stopped due to the fast emission rate in summer [1]. This result suggests that the effect of forced ventilation such as introduction outdoor air directly is likely to be transient, which is undesirable considering the effect on the indoor temperature and humidity.

In summary, it was shown that characterizing problematic chemicals and understanding their emission behaviour can be used to propose appropriate ventilation methods.

### CHANGES IN ANNUAL ACETALDEHYDE CONCENTRATION BY VENTILATION




▶ **Keywords: temporary storage, prefabricated storage, acetaldehyde, ventilation**

**[1]** E. Mizutani, M. Nakao, J. Akiyama, H. Ayae, S. Chie, *Acetaldehyde Emission Behavior and Its Reduction by Ventilation in a Prefabricated, Highly Airtight and Insulated Storage,* Conservation Science, 61 (2022), 43–55.

# Notes: