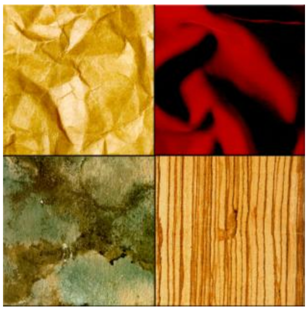
MASTER

EVK4-CT-2002-00093

Preventive Conservation Strategies for Protection of Organic Objects in Museums, Historic Buildings and Archives

Final report



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1 Introduction

Figure 1.1: The Ham House, Richmond-upon-Thames, England (Image courtesy of National Trust). Preservation of objects in museums, historic buildings and archives are affected by display and storage conditions.

All over Europe objects in museums, historic buildings or in archives are being affected either by display or by storage conditions. Unsuitable environmental conditions are a serious cause of decay, frequently made worse because the effects may remain invisible for a long period. By the time the damage is apparent the fabric and structure of an item may already have been seriously weakened. The aim of the MASTER project is to provide museums, historic buildings and archives with a new and refined preventive conservation strategy for organic objects based on an early warning system that can identify environments where damage to collections is likely.

Preventive conservation started to be recognised as a distinct branch of conservation after the publication of the important work by Garry Thomson, "*The Museum Environment*" (Thomson, 1978; 1986). Preventive conservation is a shared responsibility. It involves applying different disciplines to preservation of cultural heritage. Increasingly, preventive conservation strategies involve the application of knowledge, skill and judgement to achieve the right balance between the need to protect cultural heritage and the increasing demand for access or use. In other words, preventive conservation is focussed on eliminating or mitigating the effects of all agents of deterioration as these affect different historic materials whether on display or storage.

Most preventive conservation strategies have been created for mixed material collections. An example is Keene's mixed collection survey (Keene, 1991). Furthermore, preventive conservation strategies are often integrated with other conservation practices and museum activities (Michalski, 1994).

1.1 Scientific/technological objectives

Two of the main aims of the MASTER project were to review existing preventive conservation strategies for organic materials and to develop a new and refined preventive strategy based on an early warning system. This work was carried out by reviewing preventive conservation literature with special reference to organic materials, questionnaires to heritage institutions and through an end-user workshop exploring the views of preventive conservation experts and end-users to influence strategic developments (Taylor et al., 2003; 2004a; 2006).

The third aim of the MASTER project was the development of an early warning dosimeter system for organic objects (EWO dosimeters) that could provide a relatively cheap and easy way for museums and other cultural heritage institutions, as a first step, to evaluate the quality of the environment they provide for organic materials (Grøntoft et al., 2006).

The early warning dosimeter system consists of two dosimeters. One is a dosimeter that responds to a wide range of environmental parameters as a generic, integrating device (EWO-G). It has an accelerated response due to its manufacture from a very sensitive polymer material. Thus it is designed to give an early warning response on a 3-months timescale that can represent the long-term exposure conditions of collections and is short enough to be of practical use. The second dosimeter measures the doses of the separate gases NO_2, O_3 and SO_2 (EWO-S). A major advantage of the new dosimeters is that the dose effect can be read directly at the location after exposure, and can be interpreted by comparison with threshold levels for acceptable exposure for locations of different nature, from showcases to open displays. The threshold levels have been set based on best available effect measures for the environmental parameters on organic objects and dyes.

Both dosimeters have been tested and calibrated in the laboratory and in an extensive field test programme together with measurements of important environmental parameters (Grøntoft et al., 2005; Dahlin et al., 2005).

Up till now there has been no such early warning dosimeters for organic materials on the market. Organic materials are very complex in structure and their deterioration is a complex field with a broad range of different chemical reactions. The most prominent reactions are thermally or photo-chemically induced oxidation process and ionic hydrolysis reactions caused by acids or other catalysts (Mills and White, 1994).

Previously museums had to rely on analysing a wide range of diagnostic parameters, such as light, RH, temperature and pollution in order to control the environment. These methods are still very important, but the EWO dosimeter strategy will provide a means of surveying rapidly and simply many different environments, accounting for the synergistic effects of environmental hazards. This is particularly important for organic objects that are often present in large number in collections, such as those of historic buildings with original textile furnishings and decorations; or in libraries and archives, which hold large numbers of paper documents.

1.2 Socio-economic objectives

In addition to the scientific and technological objectives of the MASTER project presented above there are also social and economic objectives. By developing new prototype products for preventive conservation, such as the EWO dosimeters, the actual costs for conservation and restoration of organic objects can be reduced.

The MASTER project has developed a new preventive conservation strategy for organic objects based on use of an early warning system. This will contribute to minimising environmental deterioration and reduce costs of preventive conservation. By introducing a new preventive conservation strategy, the sustainable exploitation of cultural property can be enhanced.

The results obtained using the early warning system are easy to interpret and easy to visualise. This will lead to an increased awareness by, and communication between, the employees (conservators, curators, museum directors etc.) about possible decay of organic objects caused by impact of the environment. In the long term, standardised EWO dosimeters should become routine tools for assessment of indoor air quality, based on specified threshold degradation rates. This will support the implementation of EU environmental regulations (e. g. on Environmental Impact Assessment, EIA Directive – 85/337/EEC and amended EIA Directive 97/11/EC).

References see Chapter 6.1.

2 The MASTER project methodology and results

2.1 Introduction

E. Dahlin, NILU

In order to achieve the aims presented in the scientific and socio-economic objectives presented in Chapter 1, different methodological approaches were used by the MASTER consortium such as:

- Literature review
- Collection of data through questionnaires
- Laboratory and field testing and calibration of dosimeters
- Environmental monitoring and development of dose response functions
- Use of up to date and innovate instrument and data technology
- Consultations with end-users through workshops

The mix of consortium partners including both researchers and conservation staff was necessary for the methodological approach. Crucial for the success of the project development has been the qualifications and skill of the project partners in their respective fields. The MASTER consortium had four partners performing the research tasks:

- The Norwegian Institute for Air Research (NILU), NO
- The Centre for Sustainable Heritage, University College London (UCL), UK

- The Material Research Centre, Albert-Ludwigs Universität Freiburg (ALU-FMF), DE
- The Technical University of Crete (TU-Crete), GR

In addition the consortium had a broad involvement from end-users, represented by three museum partners;

- The Trøndelag Folk Museum (TF), NO
- The Historic Royal Palaces (HRP), UK
- The National Museum in Krakow (NMK), PL

and three subcontractors:

- The National Trust (NT), UK
- The Consulting and Support Centre for the Museums of Baden Württemberg (CMBW), DE
- The Wignacourt Collegiate Museum (WCM), MT

In addition, the consortium established an end-user panel of 10 members representing end-user organisations from all over Europe. This end-user panel was engaged in the project through two workshops.

Relevant literature for the research topics has been collected from a variety of international sources such as books, peer reviewed journals, conference proceedings, scientific reports and technical bulletins. The literature review identified gaps in how techniques in preventive conservation were integrated, how synergy of risks was interpreted and in the lack of knowledge about damage functions for materials, particularly for objects on open display in cultural heritage institutions.

Questionnaires were used to collect information on how European museums and cultural heritage institutions carry out their preventive conservation and assessment of environmental impact on their collections.

Laboratory work and testing in climate chambers and through an extensive field test programme throughout Europe has been essential in the development and calibration of the early warning dosimeter system.

Consultation with end-users through two workshops was important in order to make known to the consortium the end-users' requirements for a practical early warning dosimeter system, i.e. that it is easy to interpret and that it can be related to known threshold levels. The recommendations from the end-user panel have been crucial for the results of the MASTER project.

2.2 Background research

2.2.1 Preventive Conservation

J. Taylor, N. Blades and M. Cassar, UCL

Preventive conservation strategy has developed in a various directions, but gaps still exist. The MASTER project addresses the preventive conservation of organic objects in particular. The following literature review describes some of the concepts and developments within preventive conservation strategy that have defined the context of the MASTER strategy and dosimeters.

Standards and guidelines

Preventive conservation strategies had their beginning in scientific approaches to environmental monitoring and control. However, standards for organic objects have also been strongly influenced by factors outside the preservation of objects. Standards have reflected the tension between preservation and access, compromises due to available technologies, and knowledge and technology transfer from other fields, such as public health and industry.

For instance, standards for visible light exposure have had to take into account the requirements of visitors to see the objects, as well as protect objects from damage. Temperature and relative humidity (RH) conditions in a display environment must meet visitor health and comfort needs by law as well as the preservation needs of the object.

Garry Thomson, formerly scientific adviser at the National Gallery, London, was the first to define a comprehensive set of standard conditions for different kinds of museum and galleries (1978). Thomson's (1978; 1986) soundly based guidelines on appropriate conditions have been referred to as standards, and come into popular use as such in loan agreements (Ashley-Smith et al., 1994) and museum design (Padfield, 1994; ASHRAE, 2003).

Relevant standards for art objects in indoor environments.

CEN/TC 346 - Conservation of cultural property. Several standards for the conservation of cultural property are under drafting in this committee of the European Standardisation organisation.

ISO 11844. Corrosion of metals and alloys. Classification of low corrosivity of indoor atmospheres.

Practise in museums with regards to "standards" defining good or acceptable indoor environments for the conservation of cultural heritage are today usually based on most authoritative published data and recommendations based on scientific evidence for degradation effects of the environment and recommended tolerances for object degradation. This was the approach used in the MASTER project to establish environmental effect thresholds for the EWO dosimeter comparable to expected effects on organic museum objects. See chap. 2.8

Selected literature:
Thomson, G. (1986) The Museum Environment.
Tetreault, J. (2003) Airborne Pollutants in Museums, Galleries and Archives: Risk Assessment, Control Strategies and Preservation management. Canadian Conservation Institute, Ottawa.

Rate of deterioration

The admission that damage to objects is inevitable is a recent development, and expected lifetimes of objects in preventive conservation strategies more recent still (Koestler et al., 1994).

In terms of developing preventive conservation strategies, the most important consideration is the rate of change in objects. This can be predicted for certain agents of deterioration, such as visible light and UV, where colour changes have been quantified (Staniforth et al., 1994), but there is a lack of data for other risks (Staniforth et al., 1994; Ashley-Smith, 1999). Despite empirical evidence, determining rate of deterioration is very difficult, due to the number of variables, such as composition and present condition of objects (Cassar, 1995).

Assessments of changes in object condition over time have been made, using colour changes in paintings (Bacci, 1997), structural changes in canvases (Odlyha, 1998) and the effects of different concentrations of air pollutants and volatile organic compounds in European museums (Grzywacz and Tennent, 1994), but has not been carried out frequently.

Ageing studies

The rate of change in materials for different climatic conditions has been researched and rates of deterioration for different locations have been compared. For temperature and relative humidity, this is achieved using the technique of *isoperm calculations*, developed by Sebera (1994), which will be discussed further in section 2.2.2. Sebera points out that isoperms should only be used to compare different climate conditions for the effects of chemical deterioration, and not to predict lifetimes that will depend on condition and other risks (Sebera, 1994). Permanence calculations have been developed for cellulose acetate, the Time Weighted Preservation Index (TWPI), which is purported to be applicable to all organic objects (Reilly et al., 1995). Isoperm calculations have been used for climate control strategies by Pretzel (2005).

Artificial ageing has been criticised for being unrepresentative of actual deterioration (Graminski et al., 1979; Erhardt, 1987; Porck, 2000; Michalski, 2002), which compromises the concept of a preservation index, or the possibility of determining rate of change. However, Michalski (2002) comments that as an approximation, it can be practically applied in museums as a means of comparing the potential rate of decay in different environments because the conditions needed for successful study are difficult to achieve.

Natural ageing

Alternative approaches to artificial ageing are being developed. Porck states that, "a reliable judgement on the nature and rate of natural ageing can actually be made afterwards, i.e. deduced in retrospect" (2000, p. 25). Natural ageing studies have been carried out on paper (Pauk and Porck, 1996) and leather (Larsen, 1996), and methodologies devised (Taylor and Cassar, 2003) but these are not common.

Conservation Assessments

1. Value Assessment

A key principle of the Venice Charter (1964) is to preserve as much original material as possible, keeping any intervention to a minimum and doing no more than is strictly necessary, to sustain the 'life' of the original material.

Assessing the value of collections as a way of prioritising collection care only came to prominence in the early 1990s with the Dutch Delta plan. The state of collections management was assessed across the national collections to determine needs for documentation, preventive conservation, active conservation and restoration (Cannon-Brookes, 1993).

This approach has had a significant impact on preventive conservation strategy and assessments of value are now commonplace in collection surveys (Dollery, 1994; Tennison et al., 1996; Eden et al., 1998; Ashley-Smith, 1999).

In 1999, the Australian Burra Charter (Australia ICOMOS, 1999) identified that heritage value and significance may be embodied in the uses, meanings and associations of a place, in addition to the physical fabric of a place or structure. The implication for preventive conservation strategy is likely to be a change from tight environmental control for preservation and greater emphasis on context and use.

2. Environmental Monitoring

Henry (2000) suggested three different reasons for environmental monitoring in museums:

- Diagnostic monitoring
- Routine monitoring
- Validation or performance monitoring
  (Henry, 2000, p.1)

Each of these has different strategic aims and requirements. With the tendency to collect too much data and little or no analysis, which has often been the case in the past (Henry, 2000), monitoring can be an expensive process with little impact on preventive conservation strategy. Monitoring for preventive conservation fall into two categories:

- Parameter monitoring
- Dosimeter/damage monitoring

Parameter monitoring

The most frequently measured parameters in museums are temperature and relative humidity, which are monitored in most UK institutions using continuous monitoring (data logging) instruments (Cassar & Oreszczyn, 1991; Cassar, 1995, Taylor et al., 2004b). Temperature, relative humidity and light are most commonly monitored but developments in indoor pollution monitoring have been made through the use of passive samplers for gaseous pollutants (Brimblecombe, 1990) and organic acids (Grzywacz, 1993).

Figure 2.1: Indoor environmental monitoring in a museum. (Image courtesy of Trøndelag Folk Museum)

Dosimeter/damage monitoring

As well as monitoring single parameters, cumulative monitoring such as 'blue wool' dosimeters, have been developed. This is partly because environmental parameters other than radiation can affect fading, and as an alternative to spot readings. Feller (1978; Feller & Johnsen-Feller, 1978) had developed a methodology for measuring exposure of dyes to light and UV using British Standard dyes for lightfastness (BS1006). Bullock & Saunders (1999) have measured fading of blue wool using colorimeters to increase precision. A new, more sensitive dosimeter has been developed for light exposure, which also corresponds with ISO standards (Bacci et al., 2005).

Methods of monitoring actual damage resulting from the synergistic action of environmental risks have also been developed using object surrogates (Bacci et al., 1999; Odlyha et. al., 2002). A glass-based dosimeter has been developed to assess potentially damaging pollutants, as part of the EC 'Assessing and Monitoring the Environment of Cultural Property (AMECP) project, in Germany, England and Portugal (Martin, 1997).

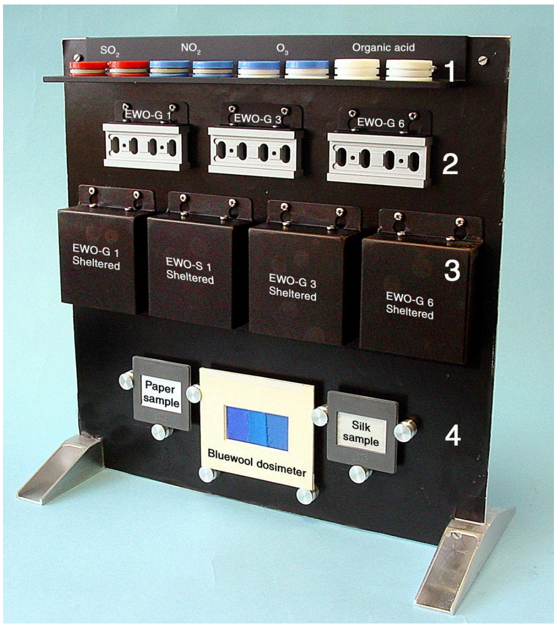


Figure 2.2: Picture: Dosimeter,- blue wool? The exposure rack for dosimeter, object and pollutant monitoring in the MASTER project.

3. Risk Assessment

Risk assessment is based on assessing the projected impact of a hazard on a collection and the probability of the hazard occurring. Hazards can be both catastrophic events (e.g. fires) and environmental factors (e.g. light damage).

This risk approach is being increasingly adopted in Europe (for example, Putt & Menegazzi, 1999; Greeves, 2001; Bradley, 2005; Brokerhof et al., 2005). The advantage of risk assessment is that it projects and prepares for what damage might occur, instead of waiting for it to happen (Waller, 2002; 2003). This way of thinking has become very influential and the number of risk assessments carried out as part of the development of preventive conservation strategies is likely to increase (Waller 2002; Waller and Michalski 2005).

Risk assessment has been further developed by Ashley-Smith (1999; 2000). Ashley-Smith (1999) suggested assessing the consequences of different possible outcomes and relating these to deterioration in terms of decisions and cost-benefit analysis. Ashley-Smith has argued that it is loss in value which is important to conservators, not loss in condition, (Ashley-Smith, 1999), since loss in condition can sometimes increase value (Michalski, 1994; Ashley-Smith, 1999). Loss in value is an important component of the risk assessment process (Waller, 2003).

Since risk assessment is largely predictive (Waller, 2002) available data about rates of change and probability of damage are insufficient to provide accurate and reliable assessment. Ashley-Smith (2000) points out that there is still a lot of uncertainty in assessing risk, and it requires data that the profession does not currently have. Uncertainty in outcomes means that predictions cannot always be accurate (Ashley-Smith, 2000).

4. Condition Assessment

The systematic assessment of the condition of collections first took place in the National Library of Congress, America (Wiederkehr, 1984) using a statistical sampling method to make a meaningful assessment of a collection of hundreds of thousands of library books. They were subsequently developed for museums by a working party from the Museum of London (Keene, 1991). Condition was assigned a number between 1 and 4 (1 = good condition; 4 = unacceptable). Sampling for museum stores has been developed (Keene & Orton, 1992; Kingsley & Payton, 1994; Orton, 1996; 2000), as well as libraries and archives (Eden et al., 1998).

Condition surveys have been used for a number of reasons, linked to both preventive and interventive strategy, and have been used as long range planning tools for preventive conservation (Shenton, 1992; Moore, 1996). Johnsen and Bonde-Johansen (2002) have used condition data and TWPI assessments to determine the most suitable storage locations for collections, although prioritisation did not involve assessment of value.

Condition surveys have been used to assess preventive conservation needs on a national level (Peacock & Sæterhaug, 1996; Holmberg & Johansen, 1996) together with the assessments of stores. There have been nation-wide assessments to gain an overview of the condition of collections.

It has been an aim of conservators to use condition surveys to assess rate of change over time (Keene, 1991; 2002; Ashley-Smith, 1999). However, comparison of condition data, between surveyors, institutions and over time have shown that data collection can be subjective (Newey et al., 1993; Taylor & Stevenson, 1999). Further criticisms of conditions surveys are that without an understanding of exposure, condition data are limited in meaning (Taylor and Watkinson, 2003) and that the assessment is retrospective (Waller and Michalski, 2005). Taylor (2005) has developed a way of integrating data about deterioration with assessment of deterministic risks.

Figure 2.3: Brodsworth library, Doncaster, England. How should conditions for cultural heritage objects and structures be assessed? (Image courtesy of English Heritage).

Integrated Strategies

Although there are several articles that deal with preventive conservation methodologies, such as collection surveys or environmental monitoring, few have integrated these into an overall strategy for preventive conservation. Some environmental management policies have been published (Martin, 1992; Bradley, 1996) but their reference to other elements of preventive conservation is limited.

Similar methodologies have been developed. For example, in Ireland, the Heritage Council uses a five-point museum assessment, including the building, the museum environment, the display and storage areas, collection condition and disaster planning are recommended to be carried out periodically (Verling & McParland, 2000). The integration or interpretation of this data is not described, however. Methodologies used in preventive conservation also exist in other countries, such as the UK (Drysdale et al., 2000) but integrated strategies are not common.

Several European countries have national conservation strategies. Scotland has published its Sterling Charter, which covers both immoveable and moveable heritage. The Netherlands had published its ‘Delta Plan’ with strong emphasis on maintenance of the heritage. Italy has implemented by law (84/90) a ‘Risk Map of Cultural Heritage’. This map is a useful instrument in determining the economic resources required for conservation and maintenance based on scientific data.

One of the most influential articles on preventive conservation strategy (which incorporates remedial and preventive conservation) has been Michalski’s ‘An overall framework for preventive conservation and remedial conservation’ (Michalski, 1990), mentioned earlier. Michalski’s (1990) nine categories of risks to collections are frequently used in museums. This was later developed further to create a systematic approach to collections management for the study and communication of collections (Michalski, 1994). The agents of deterioration had already been established, but the novelty of this approach was the integration of all these risks within one framework and is the basis for risk assessments and used in integrated strategy (Waller, 2003; Brokerhof et al., 2005; Taylor, 2005).

The notion of integrating preventive conservation into an overall museum framework was further developed in 1994 by Putt and Menegazzi (Putt and Menegazzi, 1999: Menegazzi and Putt, 2000) through ICCROM’s TEAMWORK project that brought together conservators, museum directors and other members of staff in key positions, such as security and registration to discuss the development of a preventive conservation strategy for their museum (Putt & Menegazzi, 1999).

Many strategies that integrate the conservation assessments described can be analysed in terms of collection value, exposure to hazards and consequences of deterioration. Listed below in Table 2.2.1 are the ways in which various integrated assessment methods deal with these issues.

Table 2.2.1: Table of how different assessment methodologies deal with factors of value, exposure to hazards and consequence of damage.

Assessment	Value	Exposure	Consequence
Preventive condition surveys Keene, 1991; Johnsen 1994; 1999; Holmberg & Johansen 1996	Value not assessed but curatorial surveys are recommended as a complementary assessment	**Storage** conditions and **environmental conditions** surveyed.	**Past damage** assessed similar to Keene’s (1991) eight categories
Delta Plan NMWHCA, 1992; van Huis, 1992; Cannon-Brookes, 1993	Value defined by **mission statement** and 13 point criteria outlining different kinds of value	No risk but kinds of solutions were prioritised, emphasising changes to environment over treatment	**Past damage** assessed in terms of treatment need
Risk Assessments Waller, 1994; 2003; Waller and Michalski, 2005; Brokerhof et al., 2005	Value not part of the risk equation but can be categorised elsewhere. **Loss of value** is predicted on a proportional scale.	Combines materials, as **fraction susceptible**, the **probability** of damage from a risk and **extent,** or impact, of damage	Intentional exclusion of condition but has a projected **loss of value** category in the risk equation
Angel project	**Evidential** and	**Holding maintenance**	**Existing deterioration**

Assessment	Value	Exposure	Consequence
Tennison et al., 1996; Van der Reyden et al., 1996	**informational** value assessed and combined to create a value score	**need** and **use** combined to give an exposure score	and **stability** combined to give a condition score
Preservation Assessment Surveys Eden et al., 1998	**Institutional value** is recorded because the survey is self-assessment	Combination of **accommodation**, (includes environment and housing of object) and **handling**	**Stability,** categorised by a small version of Keene's (1991) categories. Used to project future damage
Risk-condition audits Taylor, 2005	**Curatorial value** has been assessed in practice by English Heritage.	Exposure is based on risk assessment of Waller (1994)	Assesses **present** and **recent damage** but ignores past damage, damage categories relate to agents of deterioration

Future trends in preventive conservation

The development and expression of standards has become increasingly sophisticated as preventive conservation has developed. Initial standards, such as Thomson's (1986), have been developed to forge a closer relationship to cumulative deterioration of objects. The expression of pollutant levels as doses, rather than concentrations (Larsen, 1996; Tétreault, 2003), lux-hours, rather than light levels (CIE, 1995) and relative humidity cycles, rather than fluctuations (Michalski, 1993) have allowed environmental management to be guided by expected deterioration of objects, rather than performance of equipment. Classifications of standards have therefore been possible, and the development of predictions for rate of change in objects (e.g. Sebera, 1994) has created the opportunity to not only link environmental conditions to object deterioration but make generalisations about equivalent levels of damage (Michalski, 2002). This is a departure from traditional standards to recommendations that are closely linked to objects. Ashley-Smith (1999) has noted the need for object deterioration to be classified more effectively if a relationship between environment and deterioration is to be defined.

Preventive conservation strategies outside Europe are increasingly drawing upon risk assessment methodologies and decision support models (Marcon, 1997; Blades et al., 2002; Waller, 2002).

These approaches will not only change our perceptions of risks to collections in the future but the way collections are perceived may also change. It is worth repeating that the value of an object, collection or building should be a very important consideration in any preventive conservation strategy. International charters (Nara, 1994; Australia ICOMOS, 1999) are already influencing thinking within Europe and are likely to have a greater influence in the future.

Figure 2.4: Historical Museum of Baden Württemberg, Stuttgart, Germany. It is recommended that the doses to the objects of degrading environmental agents are measured instead of levels, of e.g. pollutants and light. Environmental conditions can then be linked to object condition and generalisations can be made about equivalent levels of damage.

Preventive Conservation in the MASTER project

The MASTER project has taken account of the synergistic element of chemical deterioration and has developed a dosimeter to accommodate numerous risks that are present in a number of different environments. It has integrated the interpretation of the dosimeter response with existing preventive conservation techniques, defining its relationship with each of these assessments, relating the results to object damage and the results of other preventive conservation methods.

The response is simple to read, which encourages data analysis instead of stifling it, and the visu al display encourages communication with staff, since the principle is easily understood. This allows the MASTER dosimeters to be integrated, not only with existing methods within preventive conservation but, with wider elements heritage institutions.

See figures 2.4 – 2.8.

References see Chapter 6.2.

2.2.2 Deterioration of organic objects

J. Taylor[1], K. Hallett[2], N. Blades[1] and M. Cassar[1]
[1)] UCL and [2)] HRP

Temperature and relative humidity (RH)

There are several deterioration mechanisms associated with temperature and relative humidity (RH), but the MASTER EWO-G dosimeter is primarily concerned with long-term chemical deterioration. Physical and biological deterioration processes were not art the focus of the project. The chemical deterioration of organic materials from temperature and RH requires merely the presence of these parameters, rather than a critical point being exceeded. As a result, “the goal [of preservation] becomes one of mitigating, rather than eliminating, their effect” (Erhardt and Mecklenburg, 1994, 35-36).

Temperature and RH affect all organic objects, but the symptoms of chemical deterioration can vary. Parchment reaches a gelatinous state (Hansen et al., 1992), organic dyes can fade (Thomson, 1978) and cellulosic material, such as paper can lose strength and discolour (Kolar and Strlic, 2005). These effects are strongly influenced by the material. For example, paper sizing, such as alum rosin, can significantly affect the chemistry of a book and reduce its permanence (Barrow, 1955). Strength loss in paper can reach levels (DP 200) where all its mechanical strength is lost (Emsley and Stevens, 1994).

An indirect issue is that higher temperatures and RHs increase the reaction rate of other deterioration processes, such as the deposition of pollution. Reaction rates within objects can also be increased.

The effect of temperature on chemical reaction was determined in the late 19th century by Hood and Arrhenius, stating that reaction rates can double at intervals of 10°C. Michalski (2002) suggests 5°C for conservation, Figure 2.5. RH is less well understood but known to have a similar relationship to objects – that an increase in RH will increase the rate of deterioration. The effect that is of most concern in terms of chemical deterioration is hygrothermal reaction. All organic objects are affected by this, and it is the rate of change which is the important factor.

The two parameters were combined to express the impact of hygrothermal reactions on organic objects more recently, referred to as the isoperms (Sebera, 1994). Isoperms are based on the understanding that the rate of deterioration of hygroscopic organic materials is influenced by both temperature and RH, and can be expressed as a combination. The higher the temperature and moisture content of the paper, the faster the rate of deterioration.

Isoperms are a quantified measure of the effect of these parameters combined. As mentioned earlier, Sebera (1994) developed the isoperm concept for paper, and Reilly et al. (1995) have produced permanence calculationse for cellulose acetate film. Despite the different reaction properties of organic materials, the isoperm concept is generalisable, and Michalski (2002) argues that the activation energies for most organic materials in museums fall between 95 and 140 kJ/mol.

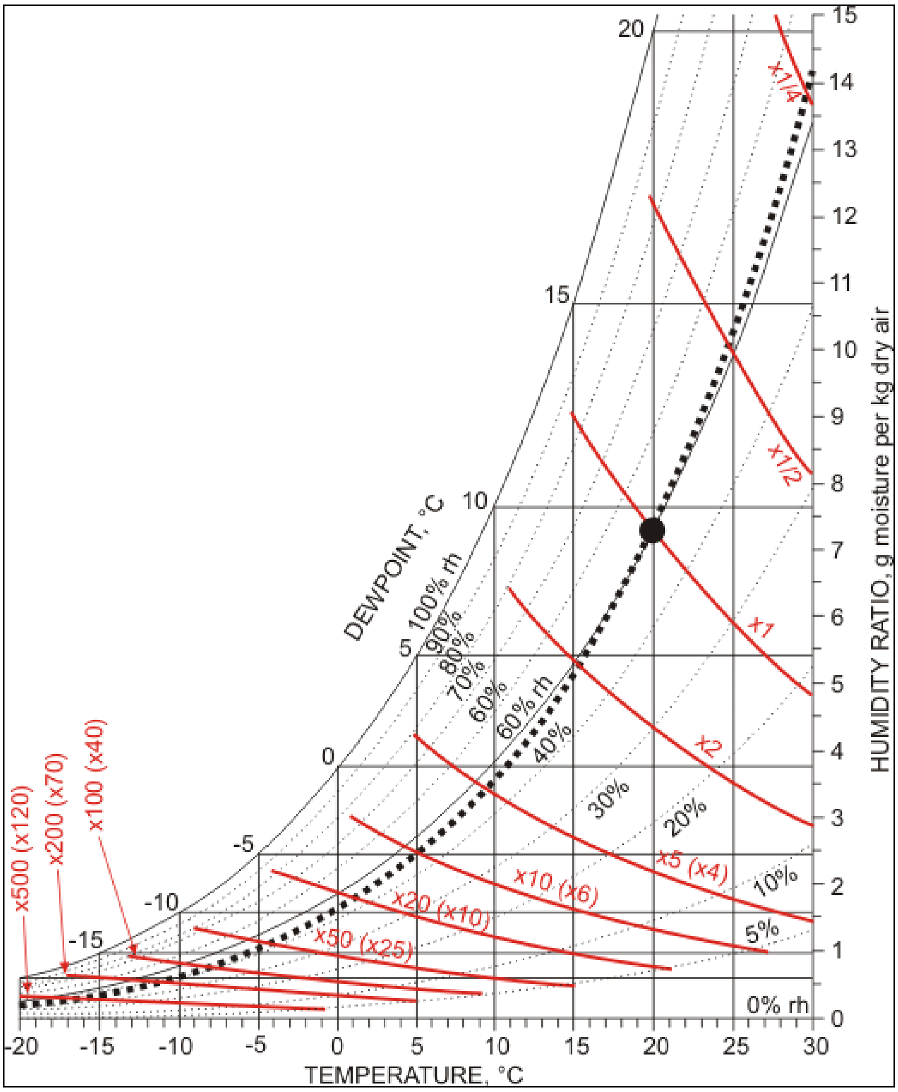


Figure 2.5: Isoperm plots on the psychrometric chart, illustrating the same reaction rates at different temperatures and relative humidities (Michalski, 2002).

Light and Ultra Violet radiation

Lighting is a pre-requisite in exhibitions for visitors to study and enjoy the collections.

However, light is one of the most important environmental factors in the deterioration of organic objects and can cause rapid damage. Light - electromagnetic radiation - is a source of energy, which will initiate and accelerate a range of chemical reactions in organic materials. Visible light (400-760nm) is therefore usually restricted where practical through the use of blinds, shutters, and dimmed artificial lighting (Cuttle, 1988). The reciprocity principle indicates that a long period of exposure to light at low levels of illumination is equal to a short period of exposure at higher light intensity.

The damage caused to organic objects from light is dependent on the dose received, but it is not linear, and also depends on the chemical components of the material. The ultraviolet (UV) component of light (300-400nm) is known to be particularly harmful, and is often filtered out in museums through the use of UV filters or coatings on window-glass. Environmental factors usually act synergistically in causing damage: the rate of light damage to organic objects is increased in conditions of high humidity and temperature (Thomson, 1994; Schaeffer, 2001).

In objects made from plant materials; light is a factor in the chemical reactions, which cause bleaching, yellowing and embrittlement. Light exposure is thought to promote oxidation rather than direct polymer chain scission. Oxidation usually results in colour change from the formation of chromophores. It also causes the formation of acidic carboxyl groups, and increased susceptibility to future hydrolytic chain scission, which results in loss of strength. Lignin and many other impurities are photosensitisers, which means that they absorb light energy in a part of the spectrum that cellulose cannot, and then transfer it throughout the cellulose, initiating degradation reactions. The degradation products of lignin are also acidic and chromophoric, which exacerbates yellowing (Bukovsky, 2000; Havermans, 1995a).

Objects made from materials with animal origin deteriorate from the effect of light exposure on constituent amino acids. The presence of tryptophan and tyrosine, for example, in silk and wool render those materials particularly vulnerable to light. These amino acids, which contain large side groups, readily absorb UV light and undergo oxidation and chromophore formation. Oxidation may again precipitate peptide bond breakages and resulting loss of material strength, or cross-linking and embrittlement (Timar-Balazsy and Eastop, 1998).

Rapid change in appearance of organic objects is often a result of fading of dyes (Saunders and Kirby, 1994). Some dyes, such as brazil wood and turmeric are particularly fugitive to light and will fade noticeably after short exposure times.

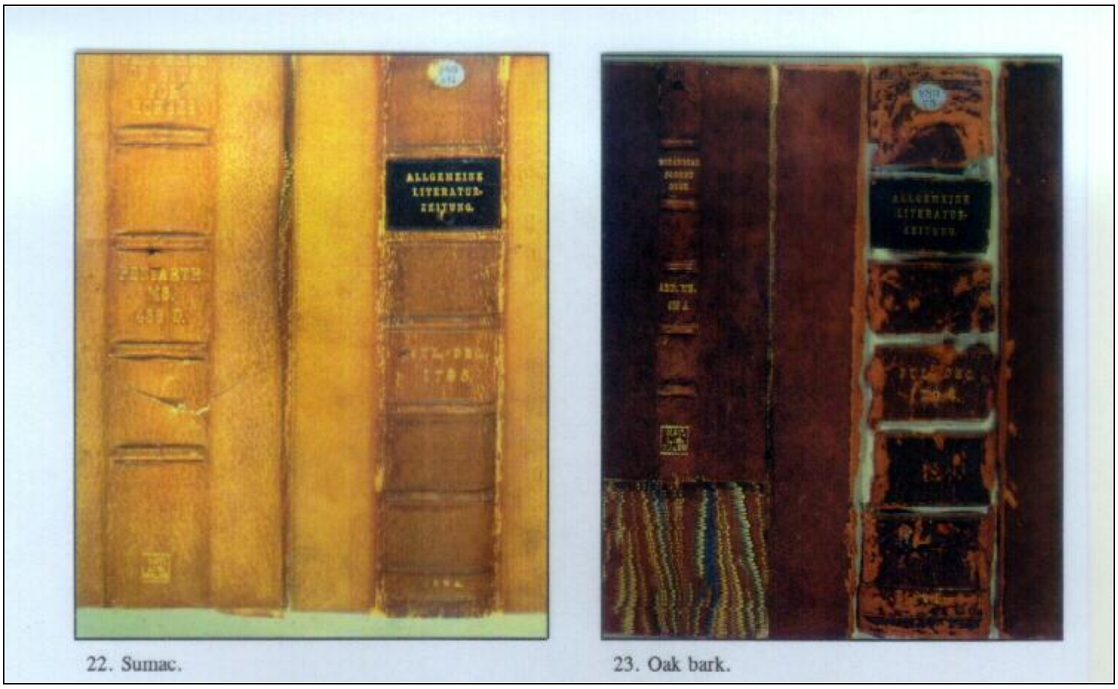
Figure 2.6: Light and particularly short wave UV radiation is an effective degradation and fading agent for organic objects.

Nitrogen Dioxide, Ozone and Sulphur Dioxide

There is a considerable body of literature on the effects of air pollutants on organic materials found in museums, art galleries, libraries and archives. This includes papers and books that review and summarise the types of deterioration that can occur, such as the early papers by Thomson (1965) and Stolow (1966). More recently Baer and Banks (1985), Brimblecombe (1990), Blades et al. (2000) and Hatchfield (2002) have reviewed and summarised the state of knowledge in this field. The most comprehensive review is that of Tetréault (2003) which presents information on the interaction between the common air pollutants and materials, based on a detailed examination of the literature of accelerating and natural ageing studies of material responses to air pollution.

Laboratory studies of the interaction of materials and pollutants have a long history. Spedding (1970; 1971 and 1972) and Spedding and Rolands (1970) with their studies of the interaction of sulphur dioxide with indoor materials were among the first to examine this area. This theme was taken up by others, for example: Grojean et al. (1988), Whitmore and Cass (1989), Daniel et al. (1992), Zinn et al. (1994) and Havermans (1995b).

Studies of natural ageing of materials are rather rarer because of the difficulties in setting up studies over long timescales or of obtaining reliable data on the pollution exposure of objects in the past. However Larsen (1996) is a notable example of such a study on the deterioration of leather book bindings and paper in library and archive collections has also been subject to natural ageing studies (Pauk and Porck, 1996).



Figur 2.7: Bookbindings degraded by SO_2 exposure. Inorganic pollutant gases are known to degrade many organic objects of cultural heritage.(Image courtesy of EC project IMPACT)

References, see Chapter 6.3.

2.2.3 Advantages of dosimetry as an environmental monitoring strategy

N. Blades[1], T. Grøntoft[2], E. Dahlin[2], J. Taylor[1] and S. Rentmeister[3]
[1)] UCL, [2)] NILU and [3)] ALU-FMF

Environmental monitoring strategies used in preventive conservation can be divided into two categories: parameter monitoring and dosimetry.

Parameter monitoring

The most common method of environmental monitoring has been parameter monitoring, where scientific measurements are made on numerical scales of relevant parameters such as temperature, relative humidity, light and air pollution. What these data mean for preventive conservation is then interpreted using background knowledge from scientific studies of the interaction between materials and levels of the parameter, either through accelerated ageing tests (see e.g. Zinn et al., 1994) or natural ageing in field tests (e.g. Larsen 1996). The latter method is much rarer than the former because of the long timescales of natural ageing and the difficulty in collecting historic data about exposure conditions throughout the lifetime of an object.

Background knowledge from these sources underpins the formulation of standards and guidelines for preventive conservation. However the data used are subject to many uncertainties such as those in extrapolating from accelerating ageing to what actually happens more slowly under ambient conditions. By contrast the methods used to measure environmental parameters are generally much more precise. It follows therefore that, at least in an early warning strategy, a semi-quantitative measure of environmental quality may well suffice. Therefore measurement by dosimetry may be entirely sufficient and has the advantages of often being easier and cheaper to carry out and often easier to interpret.

Dosimetry

Dosimetry can be thought of as the inverse of parameter monitoring: in parameter monitoring the potential for deterioration is inferred from environmental measurement. In dosimetry some form of sacrificial material that responds similarly to the materials of interest is exposed to the environment, and from its deterioration, the quality of the environment is inferred.

Some examples of dosimeters include the LightCheck devices developed as part of the EC “LIDO” project EVK4-CT-2000-00016 (Bacci et al., 2003) and blue wool standards (Bullock and Saunders, 1999), metal coupons of lead, copper and silver (Oddy, 1973). It is a characteristic of all these dosimeters that they are relatively easier to make, or cheap to buy. On the simplest level their response is a visible change. They are therefore easier and cheaper as measuring devices than most parameter monitoring techniques. They are often amenable to more detailed analysis, if needed. For instance, the corrosion layers on metal coupons can be subject to various spectroscopic analysis techniques, and the degree of light fading of a dye can either be compared with a card strip or quantified with a colour meter.

Another defining characteristic of dosimeters is that they respond in a synergistic way to the overall ‘aggressiveness’ of the environment, integrating the effects of all the different parameters present into a single response. This has advantages over parameter monitoring, where when we monitor an environment we assume we are measuring all the relevant parameters and may have to employ a range of techniques to do so. In the EC-funded project "AMECP" EV5V-CT92-0144, sensitive potash-lime-silicate glasses were used to evaluate overall corrosivity levels in museums and several glass dosimeter studies have been carried out since the end of the AMECP project in 1996 (Leissner et al., 1996).

Some dosimeters respond greatly to one factor, e.g. light fading and for practical purposes can be considered as single parameter dosimeters, but will however also respond more subtly to other factors such as air pollution and temperature. For some dosimeters the responses are more evenly distributed. For instance, the corrosion of lead coupons requires organic acids and a sufficient degree of humidity both to be present. The reaction is probably further accelerated by temperature and the presence of other pollutants. This generic response is useful for a device that is intended to give an overall indication of environmental quality. It is less useful for diagnostic purposes in that where a problem has been found, there is no clear indication of which parameter is causing the problem. In this case more diagnostic monitoring techniques would need to be employed to identify the specific cause(s) of the problem.

Dosimeters also need to respond more quickly than collections material to the environment, otherwise the information they will tell us could just have easily been obtained from examining the collections material itself. In the case of light dosimeters the response can be speeded up by using very light-sensitive dyes that would not have any practical use as pigments but are useful for dosimetry. For other materials such as silver coupons, for instance it is less obvious how their response can be speeded up compared with a silver object. In practice this can be done by making sure the surface is clean of any passivating layers oxide by scrubbing with an abrasive before exposure.

Thus, it is possible to relate the response of a dosimeter directly to the environment it is exposed in and extrapolate from this what might happen to a material we wish to conserve, in that environment. Dosimetry can also be used. , as part of a calibrated system, where the response from the dosimeter material is calibrated against an environmental quality hierarchy. This is the way it is developed in the MASTER project. In the MASTER project it was calibrated against the generic building environments, supported by literature information (see e.g. Sebera, 1994; Tétrault, 2003) on the deterioration effects of environmental parameters on materials.

From idea to dosimeter in the MASTER project

The basic technical idea in the MASTER project was that the degradation of organic materials in museums and archives by environmental stress factors could be simulated with a dosimeter made of an organic film that would act as an early warning dosimeter before harm to the objects had been observed. The idea was to simulate the changes in macroscopic and visible structure, colour or texture of a material which are in fact due to changes in the underlying chemical structure, by a well-defined and easy to measure early warning dosimeter. This dosimeter should have reactions similar to the reaction on museum objects.

Before the start of the MASTER project, NILU produced the very first dosimeters, based on a polymer film, in their own laboratory and tested them out in a few museums in the Oslo area. The dosimeters gave some promising results, but NILU needed a partner that could produce the dosimeters in a more professional way and contacted the Material Research Centre at Albert Ludwigs Universität (ALU-FMF) in Freiburg, Germany who could perform the research on the properties of different polymer films, especially their characteristics and performance.

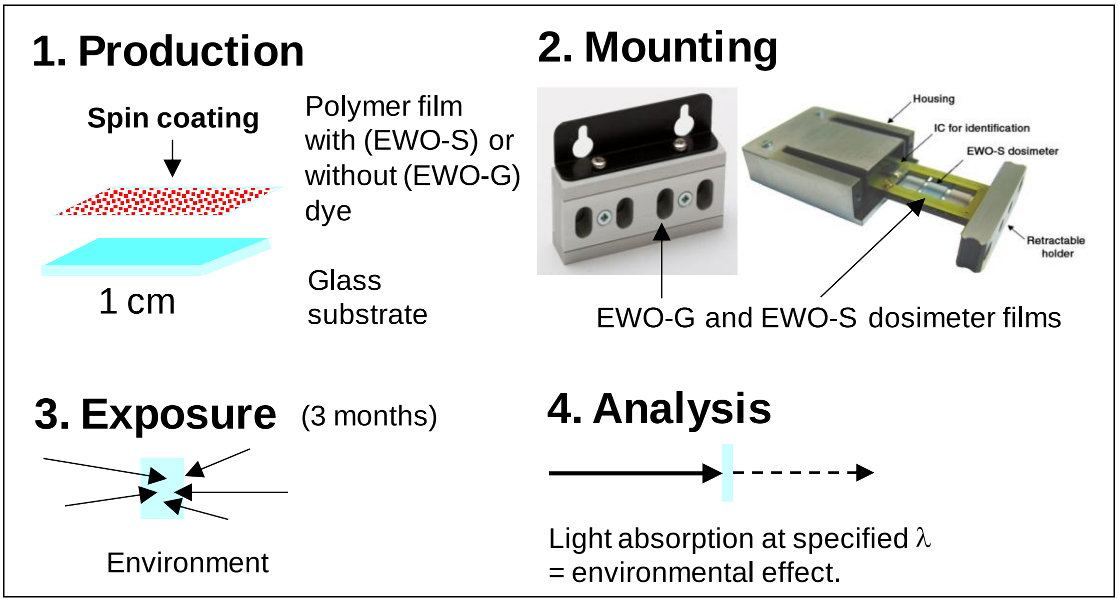


Figure 2.8: Working principle of the MASTER EWO-G and EWO-S dosimeters. a. Production, mounting, exposure and analysis of the EWO-G and EWO-S dosimeters. b. Effect of the environment on the EWO-G and EWO-S dosimeters. EWO-G: Generic effect of the environmental parameters. EWO-S: Three separate dosimeter chips with specific effects of SO_2, NO_2 and O_3

The use of a polymer film had the advantage that changes in its structure occurred much faster than in most other organic materials. In addition, such changes in a well-defined polymer material are much easier to monitor. Suitable polymers produced in form of a thin film could therefore be applied as a generic early warning dosimeter (EWO-G dosimeter) in museums or other institutions storing organic objects (Dahlin et. al., 2005). The basic concept in the MASTER project was to adapt and produce dosimeters that could easily be placed in showcases, in open display or in storing rooms. After a given exposure time these dosimeters should be sent back to a laboratory for photospectrometrical examination of the alteration of the polymer film.

In combination with the generic early warning dosimeter the aim of the MASTER project was to develop more sensitive and specific early warning dosimeters. Based on their already existing knowledge about spescific opto-chemical dosimeters, the ALU-FMF has been testing the gas permeability of 16 different polymers in combination with the testing of a number of different indicator reagents. This research has produced three specific dosimeters, for the main pollutant gases nitrogen dioxide (NO_2), ozone (O_3) and sulphur dioxide (SO_2) (Rentmeister et al., 2005).

During the research and development phase of both the generic and the specific dosimeters this early warning concept was discussed with the MASTER end-user group during two workshops. The end-user group presented their requirements to the MASTER partners. The most important was that the dosimeters should be easy to analyse at the site of exposure, preferably with some sort of visual indications.

Based on this requirement both NILU and ALU-FMF have developed a prototype of a portable measurement instrument (a dosimeter reader). A major advantage of these dosimeter readers is that the dose effect can be read directly at the location after exposure, and can be interpreted by comparison with acceptable exposure levels for different kinds of institutions, from archives to open structures. The threshold levels are set based on best available effect measures for the environmental parameters on organic objects, dyes and existing standards.

References, see Chapter 6.4.

2.2.4 Indoor/outdoor modelling

T. Glytsos, M. Lazaridis, V. Aleksandropoulou and I. Kopanakis, TU-Crete

Indoor air pollution has been associated with severe effects on human health (Spengler and Sexton, 1983) and deterioration of cultural heritage objects (Briblecombe, 1990). Extensive research effort has been invested in examining the factors influencing the indoor air quality. The results indicate that the concentration of pollutants indoors is primarily determined by the introduction of ambient air through the infiltration of outdoor air indoors, the emission of pollutants directly to the indoor air by indoor sources and their removal by deposition and homogeneous (gaseous phase) and heterogeneous (on indoor surfaces) chemical reactions (Ekberg, 1994). In the absence of significant indoor sources the air quality indoors varies proportionally to the outdoor air quality and the indoor air can be considered as an extension of the outdoor (Jones, 1999). The influence of the outdoor air quality on the indoor air quality is dependent on the climate and the building design. The meteorological conditions play an important role by determining the concentration of pollutants outdoors and also the ventilation rate (wind speed, temperature and pressure gradients). The building design and construction materials affect the transport of pollutants from different chambers within the structure and outside and the infiltration of the outdoor air indoors through openings in the building shell.

Figure 2.9: Indoor air pollution sources are outdoor air infiltrated to indoors and indoors emissions.

Several models have been developed in order to examine the influences of the above-mentioned factors to the indoor air quality. Different approaches have been adapted including mass balance, empirical – semiempirical models and models based on Computational Fluid Dynamics (CFD). More specifically, dynamic models are based on mass balance equations for describing the fate of pollutants in the indoor air (Nazaroff and Cass, 1986; Hayes, 1989; Dimitropoulou et al., 2001). These models account for the infiltration of outdoor air indoors, the emission by indoor sources and production/removal by chemical reactions. In addition their application requires experimentally resolved values on the air exchange rate and the room-mixing factor in order to adequately estimate the concentration of pollutants indoors (Chaloulakou and Mavroidis, 2002).

Moreover the deposition velocities or kinetic coefficients used are usually mean values obtained from literature or experimental estimations for different kinds of materials and no separation regarding different materials is used. The rooms are considered to be rectangular well-mixed boxes and to some of these models the exchange of air between indoor microenvironments is considered (multi-chamber models, Nazaroff and Cass, 1986; Hayes, 1989; Dimitropoulou et al., 2001). These models can only be applied for well-mixed environments where the concentration of pollutants is homogeneous throughout the room. Semiempirical models are used when large data sets from field measurements are available. Even though their application does not require air exchange rate measurements it is limited to a specific interval of environmental condition and pollutant concentration values applied during the experiments (Thatcher and Layton, 1994; Milind and Patil, 2002). Models based on computational fluid dynamics solve equations derived from mass conservation conditions to capture the spatial distribution of pollutants concentration indoors (Hayes 1991; Fan, 1995; Chen et al., 2006). Their main disadvantages are that deposition rates used are usually empirically estimated or in other cases ignored (Chen et al., 2006) and they are incapable to handle mixed-forced airflow and simulate the occupant-behaviour-related factors (Fan, 1995).

Deterioration of materials is of great importance in the case of museums, historic buildings and archives. Monitoring of environmental parameters and pollutant concentrations in indoor environments in conjunction with the application of indoor air quality models can provide useful information on the preservation of materials inside museums and historical archives. Indoor/outdoor models have been applied to museums particularly for the estimation of indoor O_3 concentration (Nazaroff and Cass, 1986; Druzik et al., 1990; Papakonstantinou et al., 2000; Salmon et al., 2000). More specifically Salmon et al. (2000) and Druzik et al. (1990) applied the mass balance model of Nazaroff and Cass (1986) to estimate the O_3 indoor concentration in several museums in the historic central district of Krakow, Poland and 11 museums in the areas of Los Angeles and San Diego California, USA, respectively. The model of Nazaroff and Cass (1986) has already been validated with experimental data in different indoor environments including museums. The above model has also been used in evaluating the impact of different preventive strategies in the protection of museum collections from damage to atmospheric ozone (Cass et al., 1990 or 91? See ref list). Papakonstantinou et al. (1999) developed a CFD model and applied it in the archaeological museum of Athens. However the model has not been validated yet with experimental data. Measurements conducted in several museums (Gysels et al., 2004; Briblecombe et al., 1999; Camuffo et al., 2001) demonstrated that the concentration of pollutants do not vary significantly within a room and between adjacent interconnected rooms. Moreover deterioration of materials is a long time process and therefore the estimation of average concentration values over long time periods is of importance in determining the adequate preventive strategy. Thus mass balance models can be efficiently applied in the case of museums, historic buildings and archives.

References, see Chapter 6.5.

2.3 Laboratory work

T. Grøntoft[1], J.F. Henriksen[1], S. Rentmeister[2], M. Hanko[2], E. Dahlin[1], J. Heinze[2], J. Taylor[3] and N. Blades[3]
[1)] NILU, [2)] ALU-FMF and [3)] UCL

2.3.1 The EWO dosimeters developed in the MASTER project

In the MASTER project two early warning dosimeters were developed. The EWO-G dosimeter responds to a wide range of environmental parameters as a generic, integrating device (Dahlin et al., 2005). It has an accelerated response due to its manufacture from a very sensitive polymer material. Thus it is designed to give an early warning response on a 3-month timescale that is representative of the average long-term exposure conditions of collections and is short enough to be of practical use.

The second dosimeter, the EWO-S consists of three different chips that measure the doses of the separate gases NO_2, O_3 and SO_2 (Rentmeister et. al 2005). It has an accelerated response due to reactive dyes mixed in stable polymer matrixes with adapted permeability. The dyes are selectively sensitive to the three different gases, with only minor interferences. The dosimeter is designed to give an early warning response after one-month exposure.

A major advantage of the new dosimeters is that the dose effect can be read directly at the location after exposure, and can be interpreted by comparison with threshold levels for acceptable exposure for locations of different nature, from showcases to open displays. The threshold levels are set based on best available effect measures for the environmental parameters on organic objects and dyes.

The technical and use characteristics for the two dosimeters developed in the MASTER project is given in Table 2.3.1.

Prior to the MASTER project there had been no such early warning dosimeters for organic materials. Organic materials are very complex in structure and their deterioration is a complex field with a broad range of different chemical reactions. The most prominent reactions are thermally or photo-chemically induced oxidation process and ionic hydrolysis reactions caused by acids or other catalysts (Mills and White 1994). Reactions caused by UV and visible light are also very important processes. However, the importance of humidity, temperature and air pollutants such as O_3, NO_2 or SO_2 should not be underestimated. All the reactions will create changes in the organic structure caused by changes in the chemical bonding and may lead to a disintegration of the object.

The EWO dosimeter strategy would provide a means of surveying rapidly and simply many different environments, both storage and display. This is particularly important for organic objects that are often present in large number in collections such as those of historic buildings with original textile furnishings and decorations; or in libraries and archives, which hold large numbers of paper documents.

Table 2.3.1: Technical and use characteristics for the two different dosimeters developed in the MASTER project.

	EWO Generic	**EWO Specific**
Technical characteristics:		
Environmental factors monitored	Generic effect of O_3, NO_2, SO_2[1] Temp, (RH[2]) and UV-light	Specific effect of O_3, NO_2 and SO_2
Technology - construction	The dosimeter chip is a polymer film (thickness ≈ 1.5 µm) spin coated on a glass substrate (15x7x1 mm)	The dosimeter chip is a polymer film mixed with a gas sensitive dye (thickness ≈ 1.5 µm) spin coated on a glass substrate (15x7x1 mm)
Technology - working principle	Environmental hazards degrade the polymer film. Bond breaking and cross-linking makes the film more opaque. The opaqueness is proportional to dose of degrading environmental influences. The dose measurement is correlated with doses known to degrade organic objects.	Gases reacts with single dyes mixed in separate polymer films. The reaction leads to a colour change of the film, which is proportional to the doses of the gases. The dose measurements are correlated with doses known to degrade organic objects.
Recommended exposure time	3 months	1 month
Immediate measurement unit	Dose observed as change in light absorption in polymer film.	Dose observed as change in light absorption in dyed polymer film.
Derived measurement unit	Will only be available when all but one of the generic effects are known from other information	Mean concentrations of the three single gases
Measurement technology	Photo spectrometry	Photo spectrometry
Measurement options	Laboratory measurement or measurement on location with handheld single wavelength instrument.	Laboratory measurement or measurement on location with handheld single wavelengths instrument.
Use characteristics		
Visible change	Yes (indirectly on handheld instrument)	Yes (indirectly on handheld instrument)
Ease of use	Simple operating procedure	Simple operating procedure
Ease of interpretation	Measurement needs comparison with acceptability chart	Measurement needs comparison with acceptability chart
Environmental impact	Inert - no impact	Inert - no impact
Size (indicating dimensions)	Holder: (8 x 2 x 0.3 cm) Handheld measurement instrument: (15 x 8 x 6 cm)	Holder: (8 x 2 x 0.3 cm) Handheld measurement instrument: (15 x 8 x 10 cm)
Durability /shelf-life	Good (months to years) when in unopened package. Increased when kept cool.	Good (months to years) when in unopened package. Increased when kept cool.
Short-long term options	Partly with dose measurement at intermediate times	Partly with dose measurement at intermediate times
Range of dosimeter sensibilities	High to medium	High to medium
Can be related to other kinds of monitoring ?	Depends on environmental data available	Yes, directly.
Diagnostic use	Depends on environmental data available	Yes, directly.
Important environmental risks NOT monitored	Light and organic acids	All (except NO_2, O_3 and SO_2)

1) At RH > 60 %
2) Isoperm adjustment of Temperature effect

2.3.2 The development and production of the EWO Generic dosimeter

The EWO Generic (EWO-G) dosimeter went through several phases of development:

1. Production of the dosimeter chips in the laboratory.
2. Testing of the dosimeter response in the laboratory and in the field.
3. Statistical calibration with combined single environmental parameters also measured in the field test.
4. Comparison with acceptable effect thresholds for organic objects.
5. Integration with preventive conservation strategy.

In addition a portable measurement instruments for easy evaluation of environments in the field has been designed.

The EWO-G dosimeter chip was produced in the laboratories of ALU-FMF in Freiburg, Germany. They used a spin coating technique with which they had previous experience (Figure 2.10).

Figure 2.10: Design of the used spin-coater.

An important part of the work of ALU-FMF was to do research on the properties of polymer films, for the EWO-G one possible polymer was polyphenylene oxide or polyphenylene ether (PPO). PPO is vulnerable both to a photochemical and chemical processes induced by light and chemical stress factors. The deterioration processes creates chain scission of the polymer, backbone and cross-linking, alteration and oxidation of side chains (Wypych, 1995). These changes can simulate the deterioration of cultural property made of organic materials. Changes in the PPO films are easily detectable by UV-visible spectroscopy. (Berre & Lala, 1989). The EWO-G dosimeter was decided to be a PPO-based dosimeter. For the EWO-G dosimeters evenness and thickness was particularly important. The carriers for the PPO-layers consisted of small glass slides (15 x 7 x 1 mm^3) of borosilicate glass, this is the same size as was used for the EWO-S dosimeters showed in Figure 2.14.

The EWO-G dosimeter has been designed with properties particularly adapted to express end-user requirements. The dosimeter has a generic response to a multitude of environmental influences that are deteriorating for organic objects. When values for some environmental parameters are simultaneously measured by other means, the dosimeter can diagnose the environment by giving a combined estimate for the remaining parameters affecting it (see description of calibration, Chapter 2.8). In this context it should be remembered that the EWO-G dosimeter is not sensitive to visible light (wavelengths over 420 nm) or organic acids, which must be measured using other methods. The dosimeter chip is small. The dosimeter chip and holder are inert and represents in itself no risk for the environment or the museum objects. In its unopened original packaging the EWO-G dosimeter has a long shelf life. Kept cool in a refrigerator the shelf life will be extended.

The prototype for the EWO-G dosimeter exists, after the development in the MASTER project, in two versions. One version is constructed in order to be sent back to a laboratory for analysis in a spectrophotometer (Figure 2.11) while the other version is for direct measurement with a portable measurement instrument at the location of exposure (Figure 2.12). A very first prototype of the portable measurement instrument (Figure 2.13) has been made.

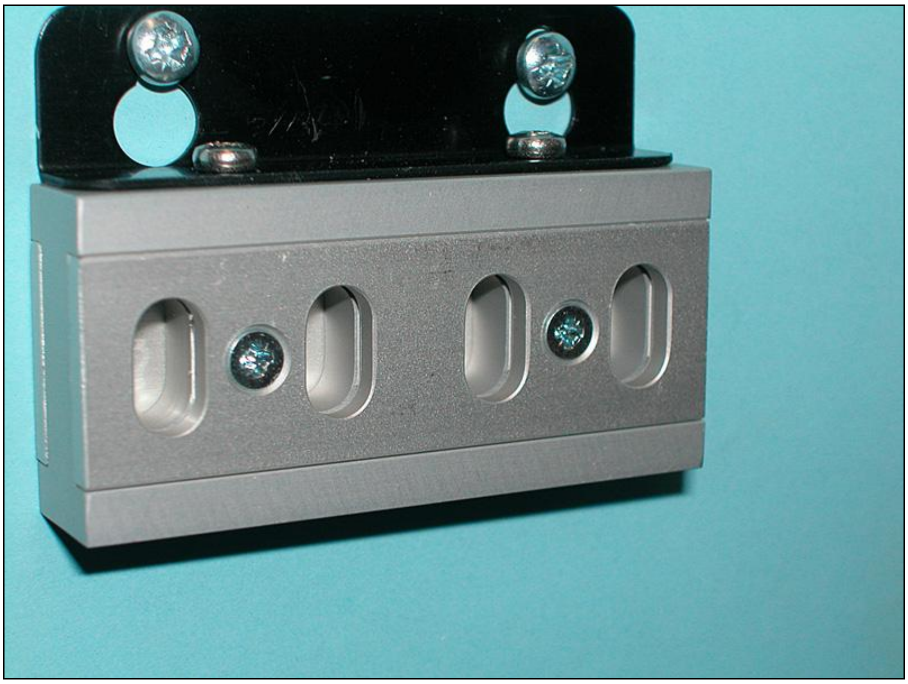


Figure 2.11: EWO-G dosimeter holder for analysis in laboratory.

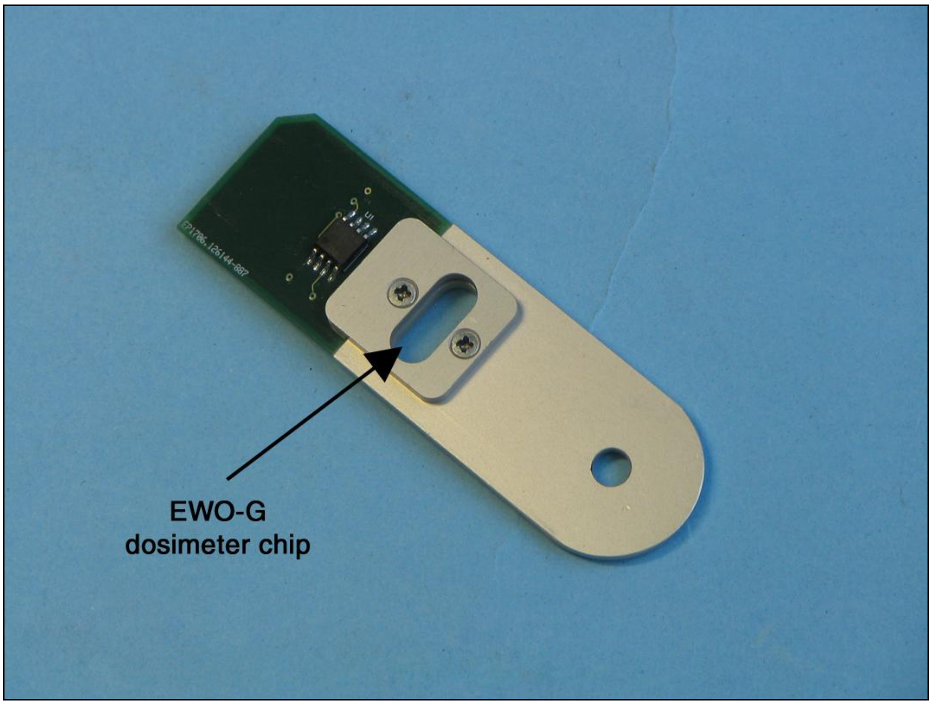


Figure 2.12: Prototype of the EWO-G dosimeter holder used for analysis in portable measurement instrument.

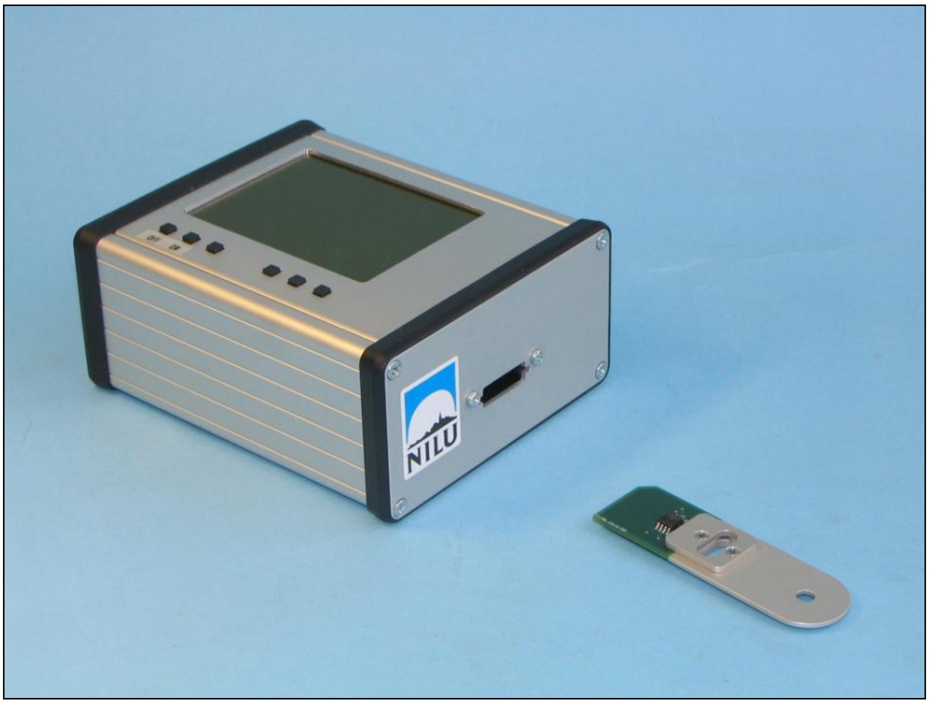


Figure 2.13: The first prototype of a portable measurement instrument for the EWO-G dosimeter.

The dosimeter system and portable measurement instrument has been designed to be easy to use and interpret. The numeral reading from the portable measurement instrument is presented as a light indicator bar in the display corresponding to the trigger level of the reading (see Chapter 2.8). In aggressive environments the dosimeter used with the handheld measurement instrument could be measured before the recommended three months of exposure for quick effect assessment or in successive intermediate intervals to assess change. With many measurements there may be some drift towards higher values. As the dosimeter integrate effects over three months it is very sensitive and can detect low concentrations or intensities of the deteriorating environmental parameters (see Chapter 2.8 for calibration values).

2.3.3 The development and production of the EWO Specific dosimeter

The EWO-S dosimeters consist of a glass carrier (15 x 7 x 1 mm³) surface coated with a thin polymer layer. Into this polymer a sensitive indicator reagent is immobilized, which is specific to an air pollutant. In the presence of this air pollutant, the absorption of the sensitive layer changes. The focus at ALU-FMF, has been the development of specific dosimeters for three main pollutant gases; nitrogen dioxide (NO_2), ozone (O_3) and sulphur dioxide (SO_2). The production of these dosimeters was done by spin-coating technique. This technique is generally applied in the semiconductor technology producing homogeneous photoresist layers (Figure 2.10).

In the case of the EWO-S dosimeters, a solution of a dissolved polymer and an indicator reagent is dispensed on a fast rotating glass carrier, whereby it spreads evenly over the carrier due to centrifugal force. After the solvent is evaporated, a homogeneous thin and transparent film remains. The sensitivity of the polymer towards specific gases can be increased by addition of selected sensitizers or dyes. By using polymers with different permeability it is possible to adjust the response time for such a dosimeter. Figure 2.14 displays two different dosimeters after the production, compared to a one-cent coin.

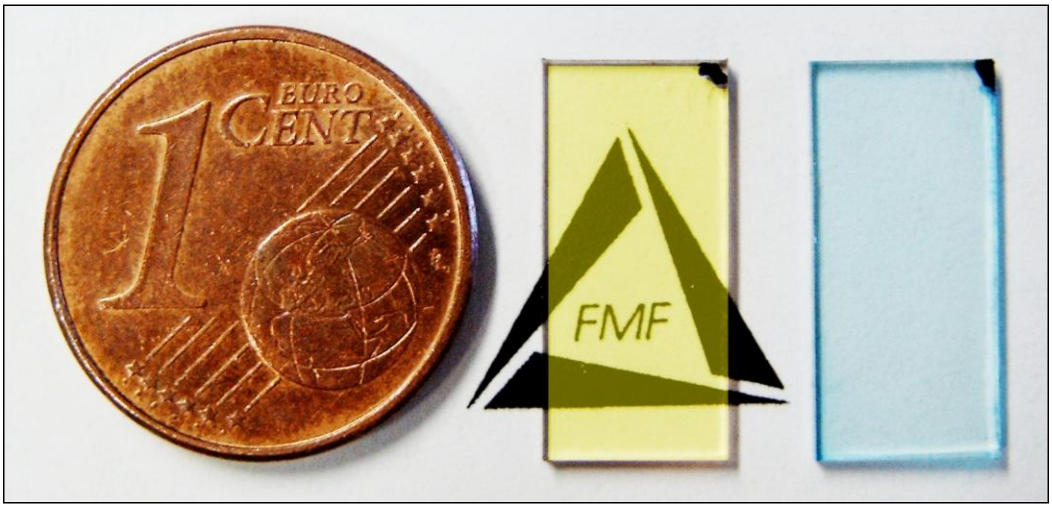


Figure 2.14: Photo of the EWO-S dosimeters compared to a one-cent coin.

As mentioned above, the main principle of these opto-chemical dosimeters is based on an irreversible change of the absorption spectra of the dosimeters in contact with the determining gas.

The prototype of the final early warning dosimeter consists of an array of three single early warning dosimeters sensitive to the gases NO_2, O_3 and SO_2. They will be packed together as a single array onto one holder, which will also contain a light shield for the protection of the dosimeters (Figure 2.16). A prototype of a hand held electronic device for the evaluation of dosimeters on site has been developed at the ALU-FMF (Figure 2.15).

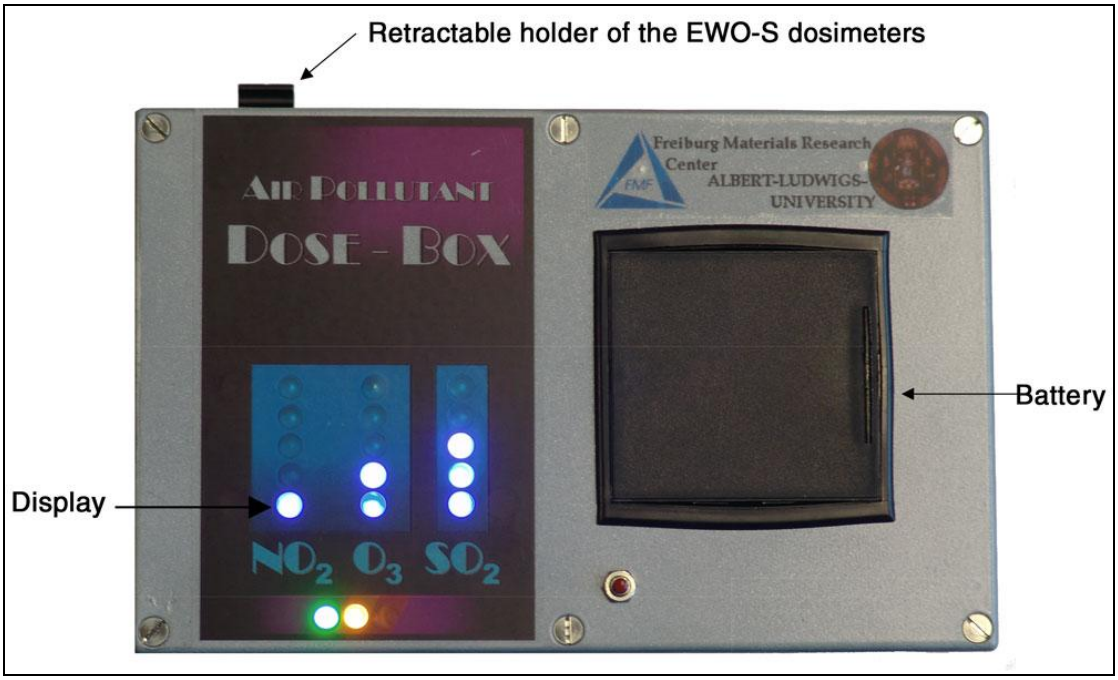


Figure 2.15: Photo of the prototype used for the analysis of the EWO-S dosimeter on site.

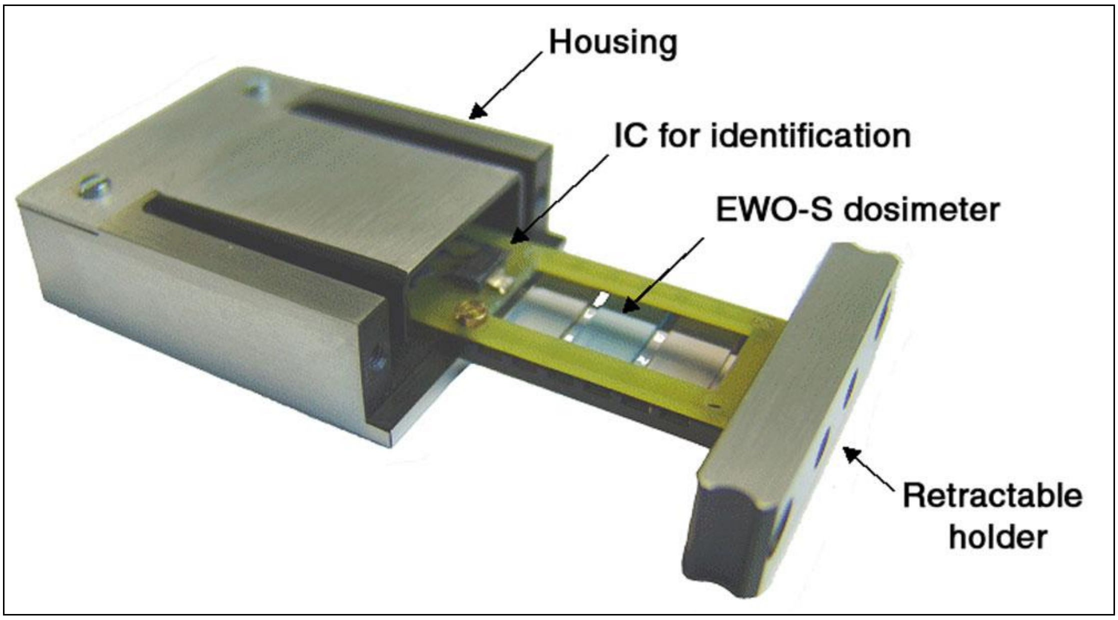


Figure 2.16: Prototype of the final EWO-S dosimeters, packed together as a single array.

The handling of this early warning dosimeter is fairly easy. Before exposure, the dosimeter array will be measured by the hand held electronic device (Figure 2.16). It will then be exposed laid out or fixed to a wall close to the works of art. After exposure, it will be measured again by the hand held electronic device.

The LED bars of the electronic device indicates the aggressiveness of the environment during exposure according to the trigger points provided by UCL Centre for Sustainable Heritage, presented in chapter 2.7, Table 2.7.1. These trigger points can be updated to actual threshold values for a best preventive conservation of materials, if necessary by connecting the electronic device to a personal computer.

2.3.4 Testing in Climate Chambers

The EWO Generic dosimeter

During the whole project period the EWO-Generic dosimeters was exposed to varying concentrations of the pollutant gases NO_2, O_3, SO_2 and acetic acid, CH_3COOH, under climatic (relative humidity and temperature) of choice. Exposure both to single and combined pollutant gases were performed in the climate chamber at NILU (Figure 2.17). The EWO-G dosimeter showed response to the three inorganic gases, NO_2, O_3 and SO_2, in the concentration range 0–100 ppb, ordinary found in indoor air. No significant response was observed for acetic acid.

A close to equal linear effect was observed for NO_2 and O_3, and for equal mixtures of NO_2 and O_3, in the range from 20 to 100 ppb at RH = 45 and 70 %. The effect was slightly lower at 100 ppb and RH = 45 % compared to that at RH = 70 %. A drop in the effect in mixtures of NO_2 and O_3, with less than equal O_3, indicated a somewhat higher effect for O_3 than for NO_2. No significant change in the effect was observed when 20 ppb SO_2 was added to concentrations of $\approx$ 60 ppb NO_2 + O_3 at RH = 45 and 70 %. No significant effect was observed for SO_2 at RH = 45 %. At RH = 70 % SO_2

showed no effect at low concentrations (< 60 ppb), but an increasing strong effect at concentrations > 60 ppb, to an effect slightly lower than that of NO_2 and O_3 at 100 ppb. No effect was observed for acetic acid at RH = 70 % even at a concentration as high as 3 ppm after a one week run. Figure 2.18 shows a comparison of the effect of NO_2 in the laboratory and in the field test.

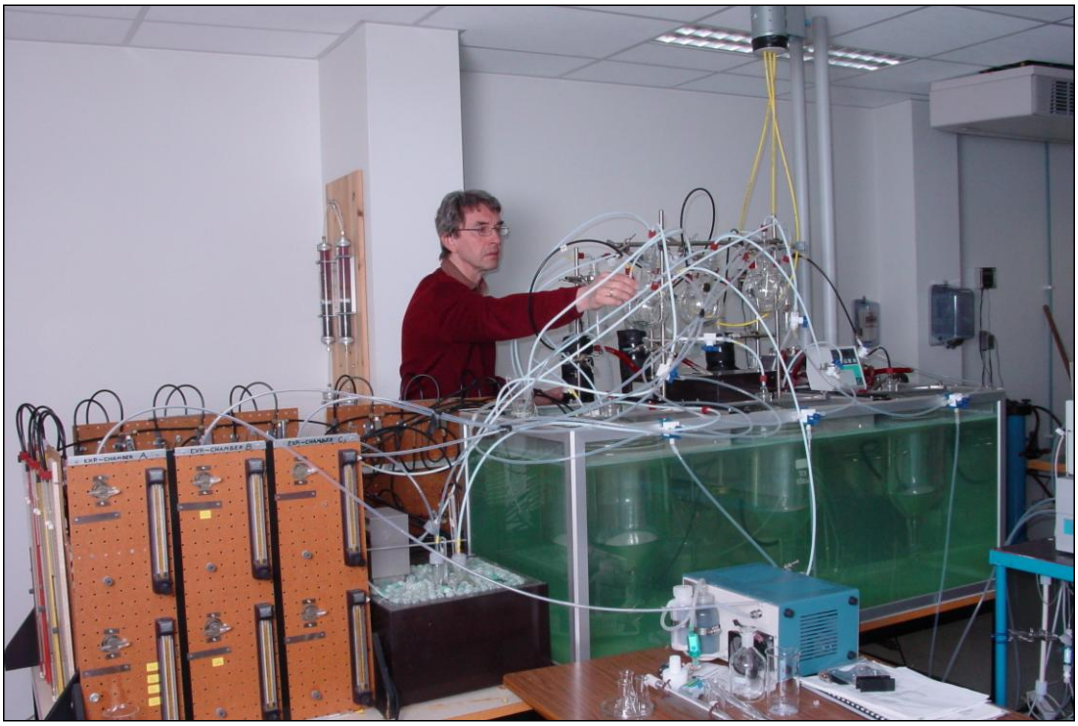


Figure 2.17: The climate chamber at NILU used for testing the EWO- G dosimeters.

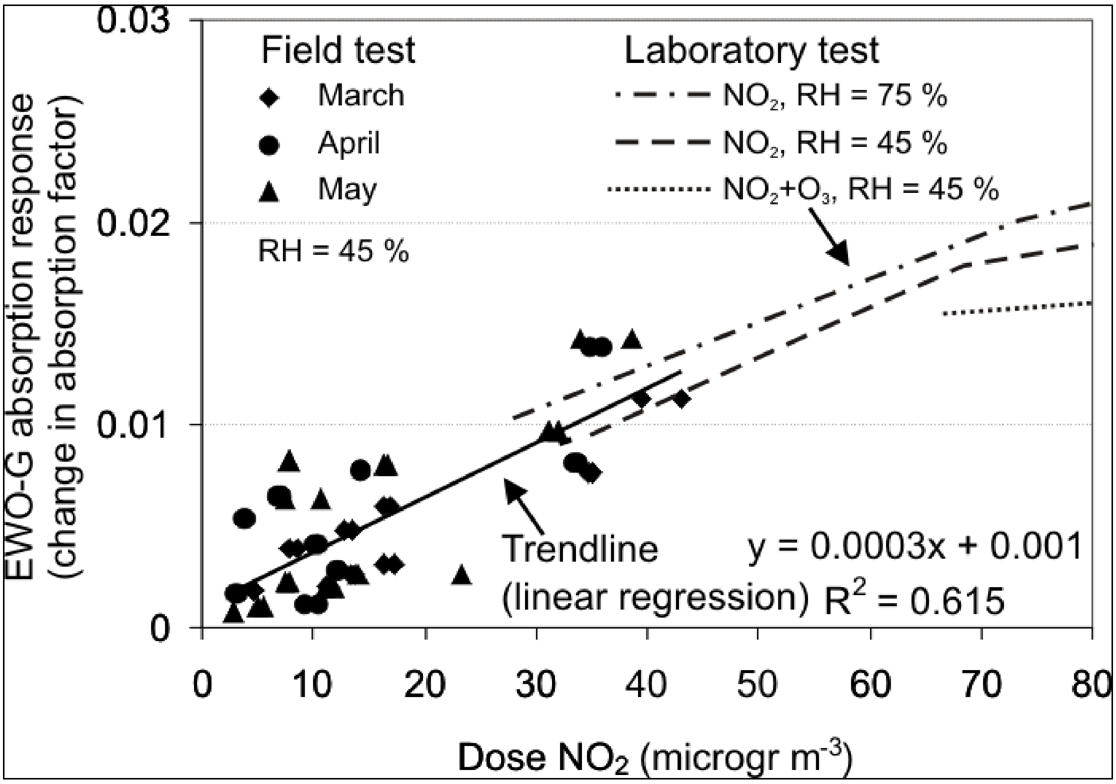


Figure 2.18: Comparison of effect of NO_2 on the EWO-G dosimeter in the laboratory and in the field.

The EWO Specific dosimeter

To simulate the conditions inside museums, historic buildings and archives, the experiments were carried out in the laboratory using flow-through desiccators, which were flushed by different air pollutants at different relative humidities (Figure 2.19). Inside these desiccators, the dosimeters were placed for several weeks under gas concentrations expected for museums (0-100 ppb NO_2, 0-50 ppb O_3 (also mixed gases) and 0-10 ppb SO_2). The airflow, relative humidity and temperature were measured, whereas the average temperature was 23°C, in accordance with the pre-settings of the application.

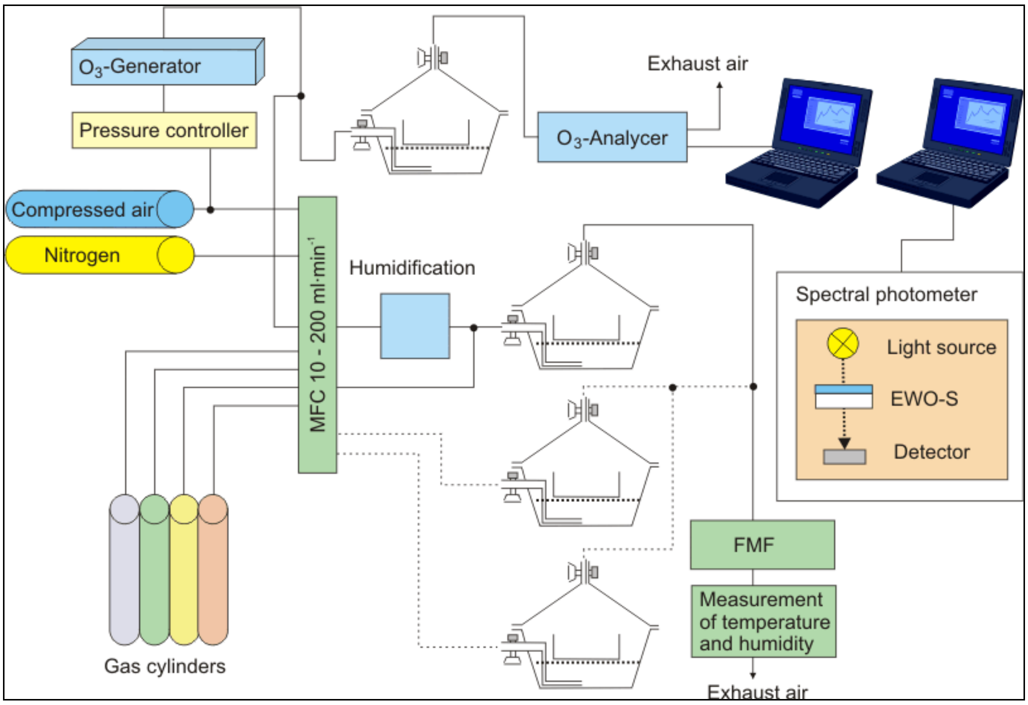


Figure 2.19: Measurement set-up for testing the EWO-S dosimeters at ALU-FMF.

In intervals of a few days, the EWO-S dosimeters were taken from the desiccators temporarily for the analysis by a spectrophotometer. The evaluation at the laboratory using a spectrophotometer was necessary at the development stage in order to characterise the behaviour of the dosimeters and to generate dosimeter characteristics. The characterising was performed by utilising the fact that the rate of absorption change is directly proportional to the gas concentration in the predetermined range. The following Lambert-Beer law was used in the analysis:

$$A(\lambda) = \log \frac{I_0(\lambda)}{I(\lambda)} = \varepsilon(\lambda) \cdot c \cdot d$$

$A(\lambda)$ ≡ absorption value at the wavelength λ of the indicator-reagent[--]

$I_0(\lambda)$ ≡ radiation intensity before EWO-S [$W \cdot m^{-2}$]

$I(\lambda)$ ≡ radiation intensity behind EWO-S [$W \cdot m^{-2}$]

$\varepsilon(\lambda)$ ≡ absorption coefficient of the indicator reagent [$l \cdot mol^{-1} \cdot cm^{-1}$]

c ≡ concentration of the absorbing indicator reagent inside the polymeric layer [$mol \cdot l^{-1}$]

d ≡ thickness of the sample [cm]

Inside the polymeric layer the concentration of the indicator reagent changes during reaction with the determining gas, which leads to a change in light absorbance. The dosimeter characteristic curves are based on the absorption change of the indicator reagents at a single wavelength. This enables the use of the hand held electronic device with cheaper light emitting diodes (LEDs) and photo detectors, instead of a spectrophotometer, during routine use. Hence, the end user will need no spectrophotometer.

Requirements for the development were, that the dosimeters should be passive (without further electronic equipment) and that they should be exposed for several weeks. Therefore, the used indicator reagents and polymers had to fulfil different requirements. The most important are listed in the following. For a specific determination of concentrations of air pollutants, the reaction of the indicator reagent with the gases must be as specific as possible. Due to the long exposure times, the primary reaction product must not have follow-up reactions. Therefore, 60 different purchased and self-synthesised indicator reagents (antioxidants, redox indicators or amines for the determination of NO_2 and O_3 (Hulanicki and Glab, 1978; Lipari, 1984; Lambert et al., 1989; Ohm, 1993; Cataldo, 1996; Ralfs and Heinze, 2005; Alexy et al., 2005a; Alexy et al., 2005b) and oxidants for determination of SO_2 (Hanko et al., 2004) were tested in order to find the most suitable reactive components. Additionally, the polymers should be inert and be able to immobilise the indicator reagent well over time. Because of the measurement in transmission mode, they also have to be optically transparent.

The exposure time of the dosimeters will be approximately four weeks, which was one of the requirements emerging from the end-user workshops. Hence, one of the most important factors in the composition of the dosimeters is the polymer and its characteristic gas permeability (Mark et al., 1968; Vieth, 1991; Michell, 1830; Fick, 1855;Wijmans and Baker, 1995). According to the specifications of the dosimeters (exposure time, expected concentration range of air pollutant) polymers with a broad range of gas permeabilities had to be tested in order to find the most suitable ones for the different applications.

In use, the EWO-S dosimeters will be measured once before and then after exposure, at a certain wavelength. The change in absorption gives the information about the average gas concentration during exposure. To be able to use standard (cheap) light-emitting diodes for the measurements the possible indicator reagents were reduced to those, which have a sufficient change in absorption at wavelengths higher than about 380 nm. Using this type of measurement for analysis the change in absorption must be directly proportional to the exposure time at a constant gas concentration.

Figure 2.20 displays this necessary linear change in absorption at 390 nm over the exposure time using a composite which consists of 16 wt% diphenylamine immobilised in polycarbonate under the influence of NO_2.

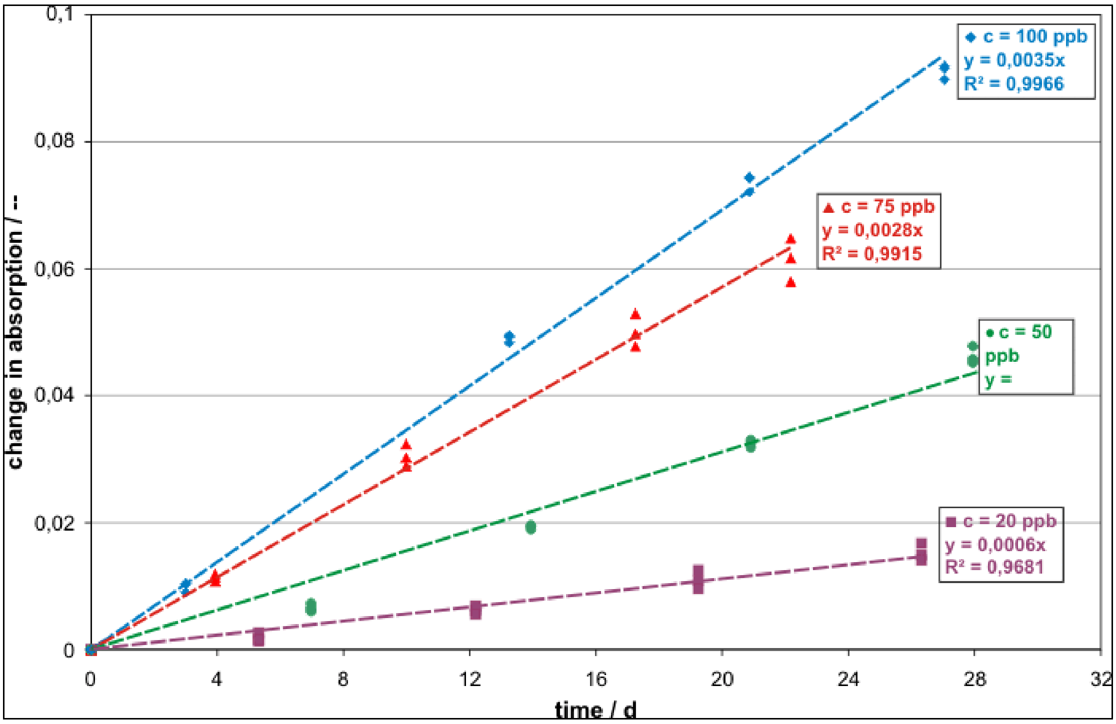


Figure 2.20: Linear change in absorption at 390 nm of 16 wt% diphenylamine immobilised in polycarbonate under the influence of NO_2.

In the following, the specifications of the developed EWO-S dosimeters and their characteristics are listed:

The NO_2-sensitive dosimeter

The NO_2-sensitive dosimeter consists of 16 wt% diphenylamine immobilised in polycarbonate and was prepared from a solution in chloroform.

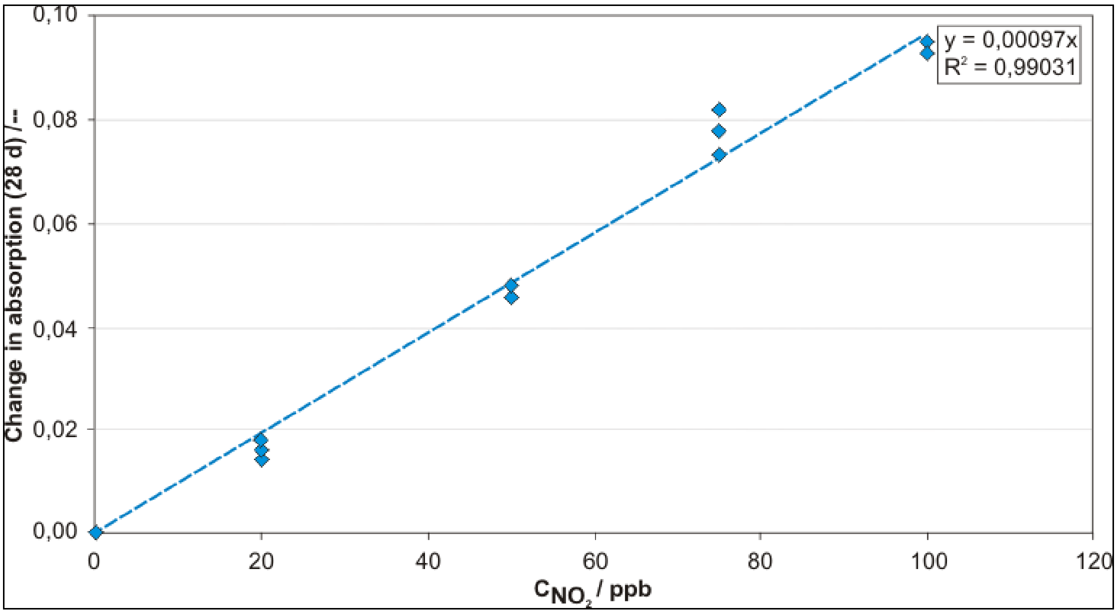


Figure 2.21: Characteristic of the NO_2-specific EWO-S dosimeter.

$$c_{NO_2} = 28112\, ppb\, d \cdot \frac{\Delta A(t)}{t\, d}$$

The detection limit, calculated according DIN 32645, was found to be 3,46 ppb NO_2 with a probability of error of 5 % and an exposure time of t = 28 days. The upper limit of determination is far beyond 100 ppb NO_2 per day during an exposure time of 28 days as the linear graph in Figure 2.21 shows, and therefore it fulfils the requirements for gas analysis inside museums with lower concentrations. No significant influence of relative humidity has been observed. An unacceptable cross sensitivity towards O_3 was observed. Above a certain O_3-concentration, the NO_2-sensitive dosimeter will not function properly, since the indicator-reagent will be destroyed by O_3. The low O_3-concentrations inside the museums in the field test seamed to have no significant influence on the dosimeter results. It was however not possible to define the limiting concentration of O_3 in the laboratory.

The O_3-sensitive dosimeter

The O_3-sensitive dosimeter consists of 9 wt% of 7,7'-dimethoxy-4,4'dinonoxy-indigo immobilised in polycarbonate and it was also prepared from a chloroformic solution.

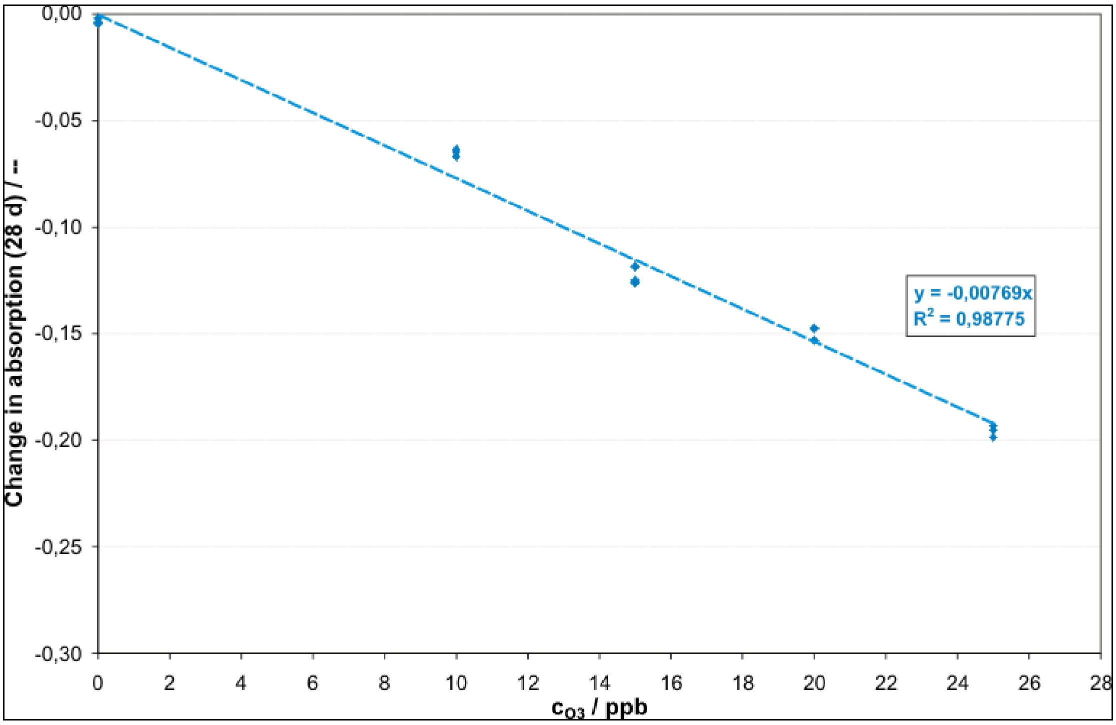


Figure 2.22: Characteristic of the O_3-specific EWO-S dosimeter.

$$c_{O_3} = -3642{,}7\, ppb\, d \cdot \frac{\Delta A(t)}{t\, d}$$

The detection limit according DIN 32645 was found to be 2,84 ppb O_3 with a probability of error of 5 % and an exposure time of 28 days (relative humidity (rH) < 5%). The upper limit of determination is about 30 ppb O_3 per day during an exposure time of 28 days (Figure 2.22). There is only a little cross sensitivity towards NO_2. To quantify this cross sensitivity, the O_3-sensitive dosimeters have been tested in an atmosphere of 100 ppb NO_2 (28 days of exposure), which gave a dosimeter response equal to that for an O_3-concentration of 6,2 ppb, but the composite used for the O_3 sensitive EWO-S dosimeter is influenced by humidity. Experiments with relative humidity values between 0 and 61 % rH showed decreasing change in absorption with increasing humidity.

The SO_2-sensitive dosimeter

The SO_2-sensitive dosimeter consists of 33,3 wt% N,N,N,N-tetrabutylammonium dichromate immobilised in Poly-(dimethylsiloxane)-*b*-polycarbonate prepared from a chloroformic solution under red light.

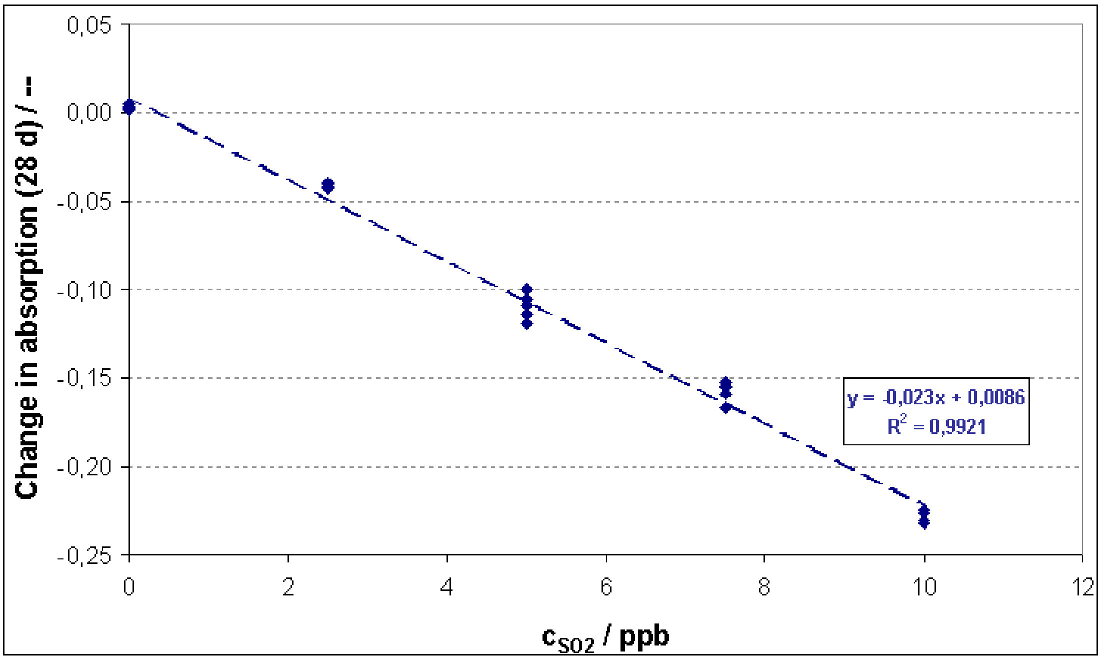


Figure 2.23: Characteristic of the SO_2-specific EWO-S dosimeter.

$$c_{SO_{2\,3}} = -1217{,}7\ ppb\, d \cdot \left(\frac{\Delta A(t)}{t\, d} + 3{,}06 \cdot 10^{-4}\ d^{-1} \right)$$

The detection limit according DIN 32645 is 0,72 ppb SO_2, with a probability of error of 5 % and an exposure time of 28 days (rH < 5%). The upper limit of determination is around 3 ppb SO_2 per day during an exposure time of 28 days (Figure 2.23). The used composite for the SO_2 sensitive EWO-S dosimeter is influenced by humidity. Experiments with relative humidity values between 0 and 80 % rH have shown increasing change in absorption increasing humidity. Additionally, higher relative humidity values accelerated a crystallisation of the indicator reagent, that was already a problem during storage of the dosimeters. In preliminary experiments other polymers were tested for the immobilisation of the indicator reagent. Silicone rubbers and amphiphilic co-networks are very promising materials for this purpose.

References see Chapter 6.6.

2.4 Field test in European museums

T. Grøntoft[1], E. Dahlin[1], S. Rentmeister[2], K. Hallett[3], M. Lazaridis[4], J. Czop[5], A. Sommer-Larsen[6], C. Calnan[7], C. Pitzen[8], JA. Cassar[9]

[1)] NILU, [2)] ALU-FMF, [3)] HRP, [4)] T U-Crete, [5)] NMK, [6)] TF, [7)] NT, [8)] CMBW, [9)] WCM

2.4.1 The content of the field test programme

The environmental effect on organic materials in museum, historic buildings and archives is mentioned in the literature (Thomson 1986, Mills and White 1994), but scarcely quantified. The results from Questionnaires research in the MASTER project showed that many European Museums and Historic buildings were unaware of the effects of certain risks, especially pollutants (Taylor et al., 2004b). The dosimeters developed by the MASTER project will assess expected deterioration rates of organic objects due to the influences of the air environment and particularly of the contaminants in it. To test the dosimeters and to calibrate them against the environmental parameters and to reference materials like paper and silk, an extensive field test programme was carried out for 12 months from March 2004.

In the MASTER field test programme 10 different museums or historic buildings from 5 different regions in Europe were selected (2.4.1). In order to obtain a classification system for the risk of damage the field test sites selected had different environments from low to severe aggressiveness. In each of the 5 regions one rural site with low pollution and one urban site with higher pollutant levels were selected to obtain the variations needed.

2.4.1: Museums participating as exposure and monitoring locations in the MASTER project field test.

Name of museum/ historic building	Location *, Country	Site number
The Museum of Decorative Arts & Design	Oslo, Norway	1
Trøndelag Folk Museum	Trondheim, Norway	2
Blickling Hall	Norfolk, UK	3
Tower of London, Bloody Tower	London, UK	4
Haus der Geschichte Baden-Württemberg	Stuttgart, Germany	5
Schwarzwälder Trachtenmuseum	Haslach, Germany	6
National Museum in Krakow, The Jan Matejko House	Krakow, Poland	7
The Karol Szymanowski Museum “Atma”	Zakopane, Poland	8
Wignacourt Collegiate Museum	Rabat, Malta	9
The Historical Museum of Crete	Heraklion, Crete	10

*Only name of location will be used in the graphs presenting the monitoring results.

The field test was performed with separate exposures outdoors (A), (Figure 2.24), indoors in the exhibition area (B) (Figure 2.25) and inside showcases (C) (Figure 2.26). In all three locations the EWO-G and EWO-S dosimeters, the passive samplers, and samples of organic objects; paper, silk and blue wool light dosimeters, were placed on an exposure rack (Figure 2.27) specifically designed for the MASTER field test. Measurement instruments and loggers for the climatic parameters (T, RH and Light) were place on the same location as the exposure rack.

Figure 2.24: Test site A-outdoors, on the roof of the museum "Haus Der Geschichte Baden Württemberg", Stuttgart, DE.

Figure 2.25: Test site B - exhibition area, inside the "Bloody Tower". Tower of London, UK.

Figure 2.26: Test site C- showcase, at the Trøndelag Folk Museum, Trondheim, NO

The exposure rack and a technical manual for the field test programme were delivered from NILU to the different test sites. On the rack, parallel samples of passive gas samplers for O_3, NO_2, and SO_2, (including organic acids in location C) were mounted in order to obtain mean monthly values of the gas concentrations. Parallel samples of EWO-G dosimeters were exposed shielded from light and fully exposed to the light. This made it possible to study the light effect separately. The EWO-S dosimeters were only exposed shielded from light. One, three and six months samples were exposed for both types of dosimeters. Blue wool samples were exposed on the rack to make a separate direct evaluation of the light exposure. Side by side with the EWO dosimeters, samples of silk and paper were exposed for one year with the aim of assessing any degree of deterioration during the exposure period.

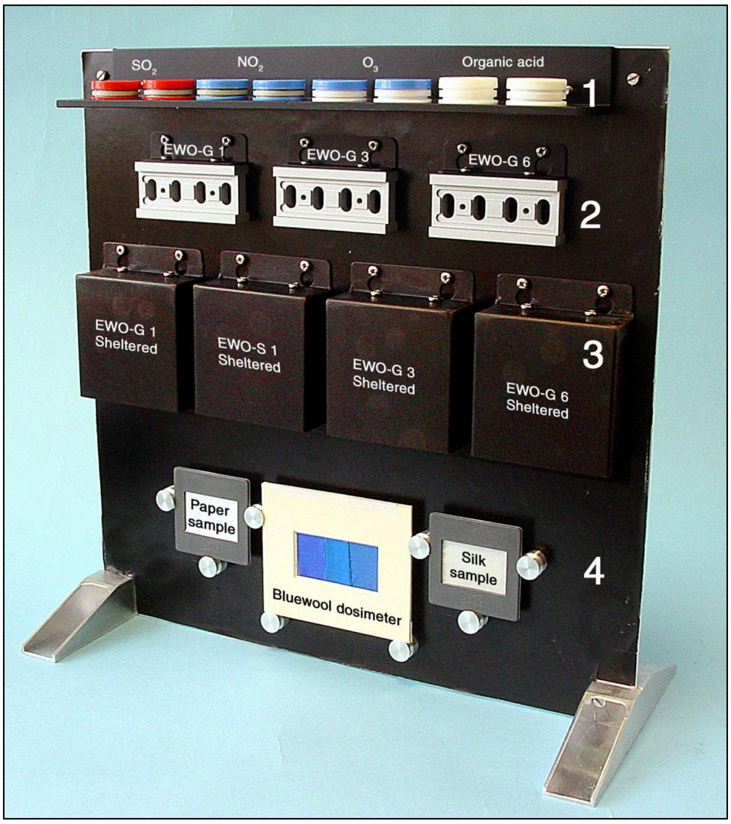


Figure 2.27: The MASTER field test exposure rack.
1) Passive gas samplers, 2) Unshielded EWO-G dosimeters,
3) Shielded EWO-G and EWO-S dosimeters,
4) Exposed paper and silk samples and Bluewool dosimeter.

Temperature and Relative Humidity were monitored and logged continuously for locations B and C with a resolution of 1 h or less. Mean monthly values were calculated from the logged values and reported. For location A, gathering of monthly averages data from local meteorological stations were reported. Light as lux and UV as mW m^{-2} were measured in the locations B and C at 12 o'clock noon as a single spot measurement and it was monitored continuously for periods in some sites depending on the stability in the lighting conditions, - e.g. if there was only artificial lighting, only natural light or some combination of the two. Mean yearly values were reported.

The passive gas samplers and the dosimeters were sent back from the museums to NILU for analysis in the laboratory. All environmental and monitoring data were reported to NILU who was responsible for building up a database to be used in the evaluation of the dosimeters.

2.4.2 Results from monitoring of environmental parameters

The values for the environmental parameters showed a relatively good spread between the museums, which made them fit for statistical analysis. For the gas concentrations and material effects the values for the showcases were generally lower than the indoors values where as values for outdoors were generally higher than the indoors values, with only a few exceptions (Figure 2.29). The relative values of the climatic parameters in the showcases, indoors and outdoors depended much more on the season than for other parameters. Light values (Lux and UV) were only collected as yearly mean noon values. This made evidence from the laboratory tests regarding the light effect important. Figure 2.28 to Figure 2.37 show the monthly values measured for the environmental parameters, indoors in the museums, which were used in the calibration of the dosimeters. The calibration levels for the separate parameters, which are given below in Chapter 2.8, are included in the figures.

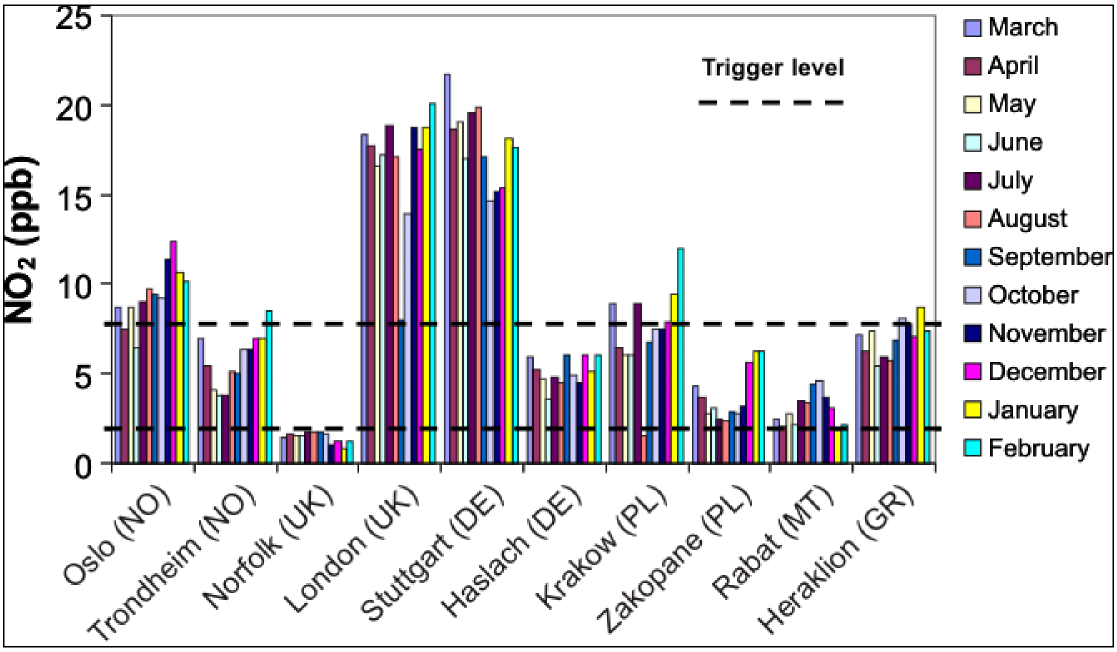


Figure 2.28: Indoors NO_2 at site B, in the10 museums depending on season.

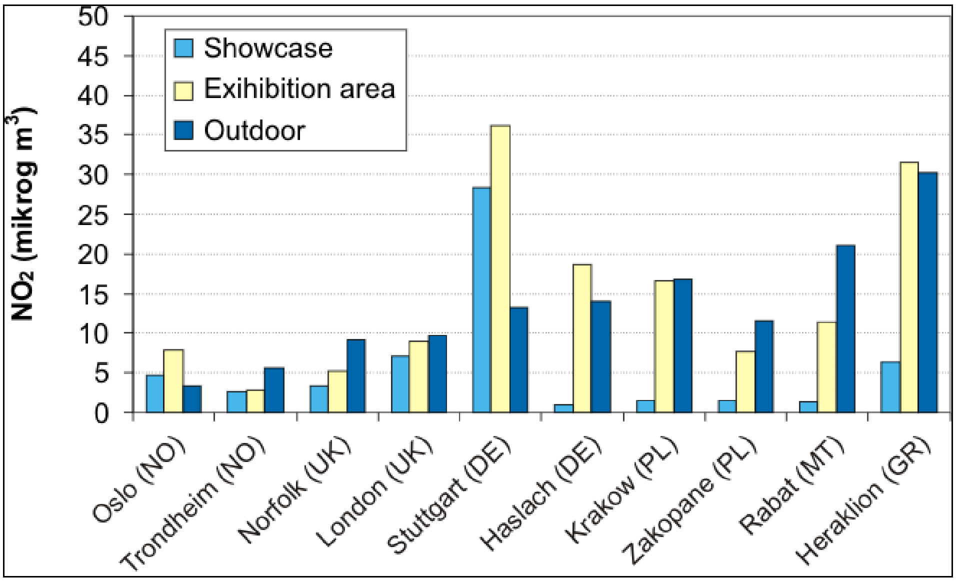


Figure 2.29: NO_2 concentrations in May 2004, dependent on location of measurement.

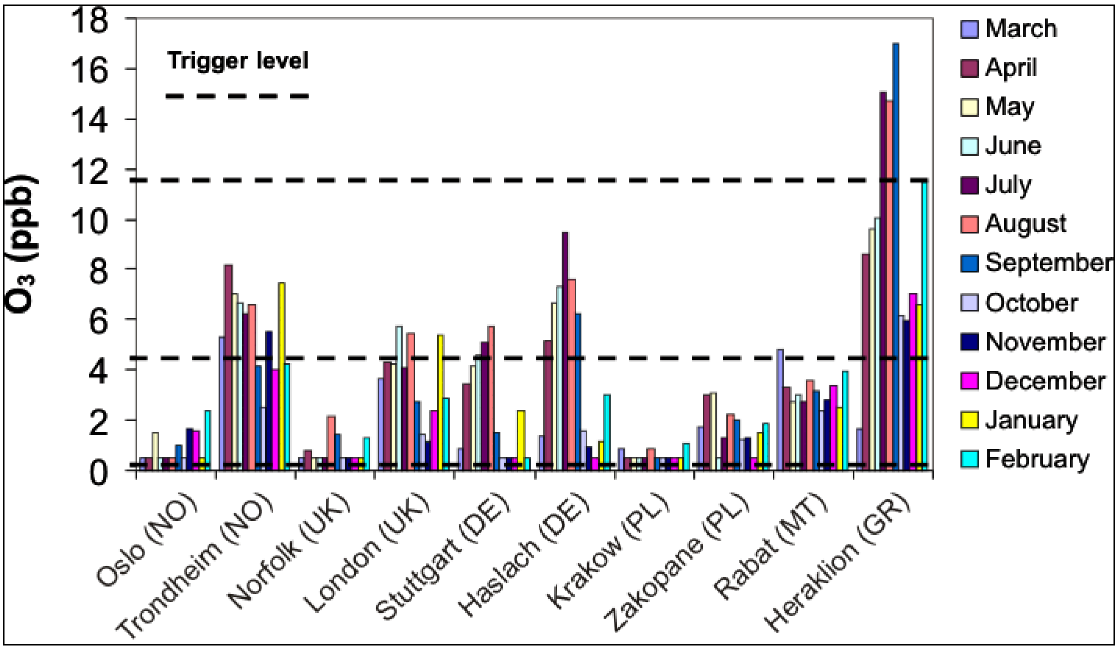


Figure 2.30: Indoors O_3 at site B, in the10 museums depending on season from March 2004-February 2005.

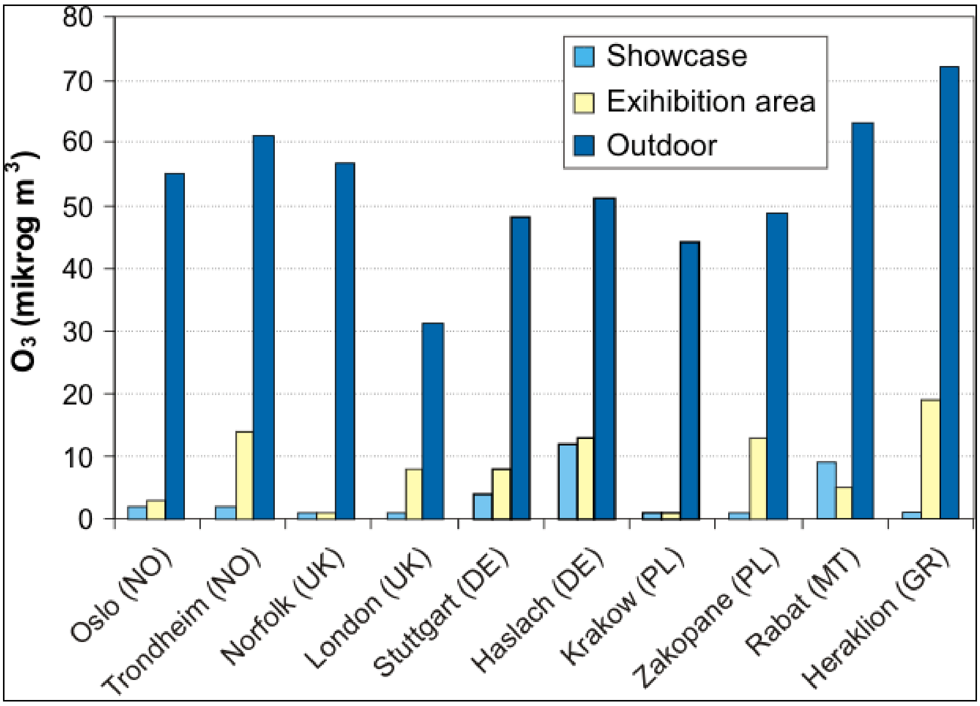


Figure 2.31: O_3 concentrations in May 2004, dependent on location of measurement.

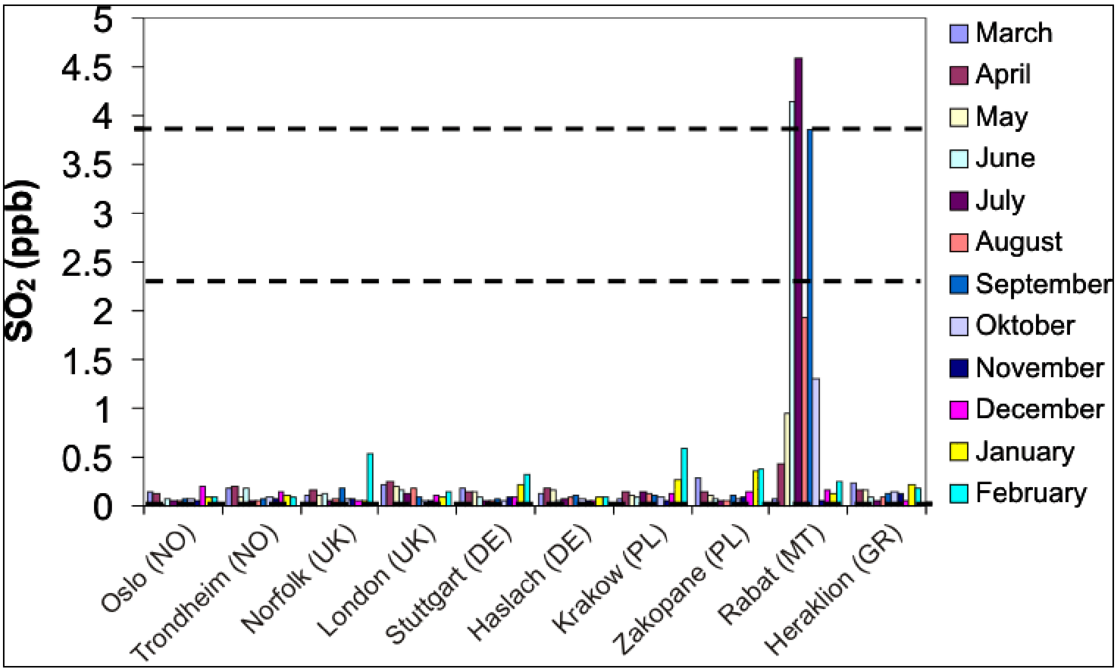


Figure 2.32: Indoors SO_2 at site B, in the10 museums depending on season from March 2004-February 2005.

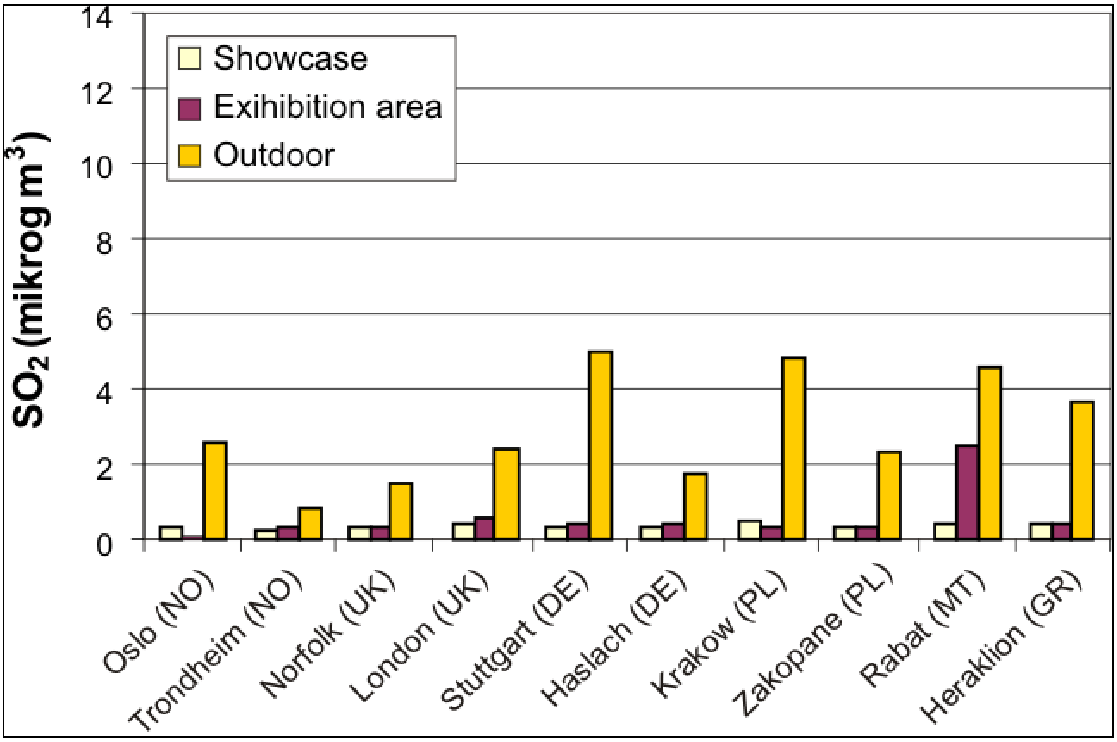


Figure 2.33: SO_2 concentrations in May 2004, dependent on location of measurement

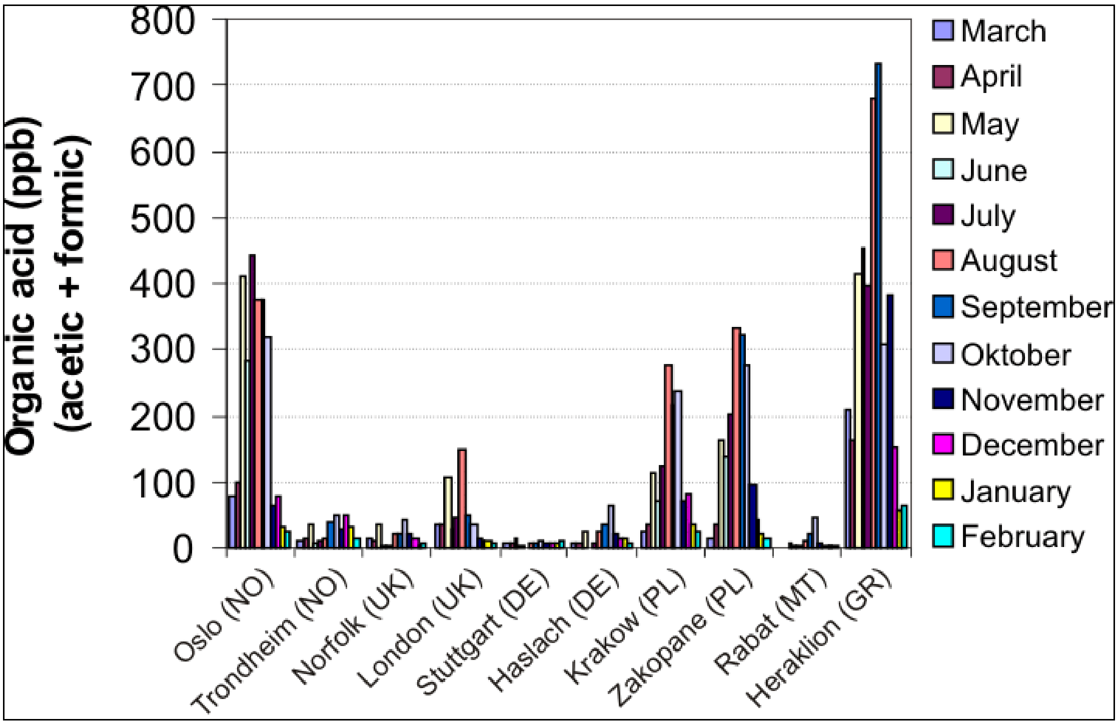


Figure 2.34: Organic acids in showcases the10 museums depending on season from March 2004-February 2005.

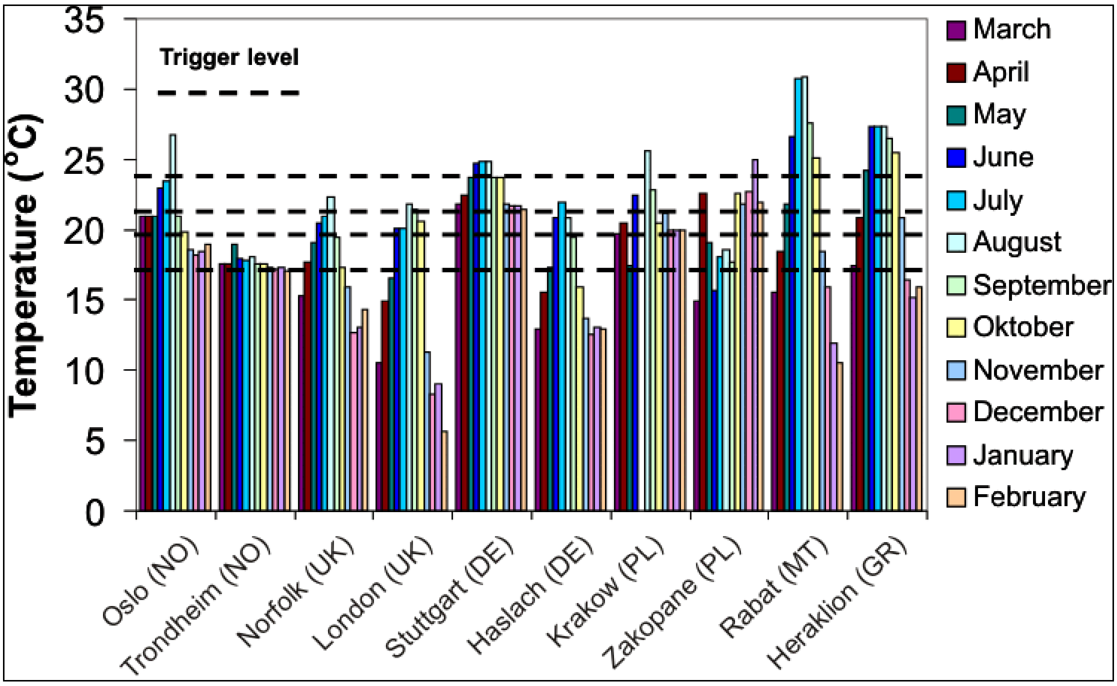


Figure 2.35: Indoors temperature in the10 museums depending on season from March 2004-February 2005.

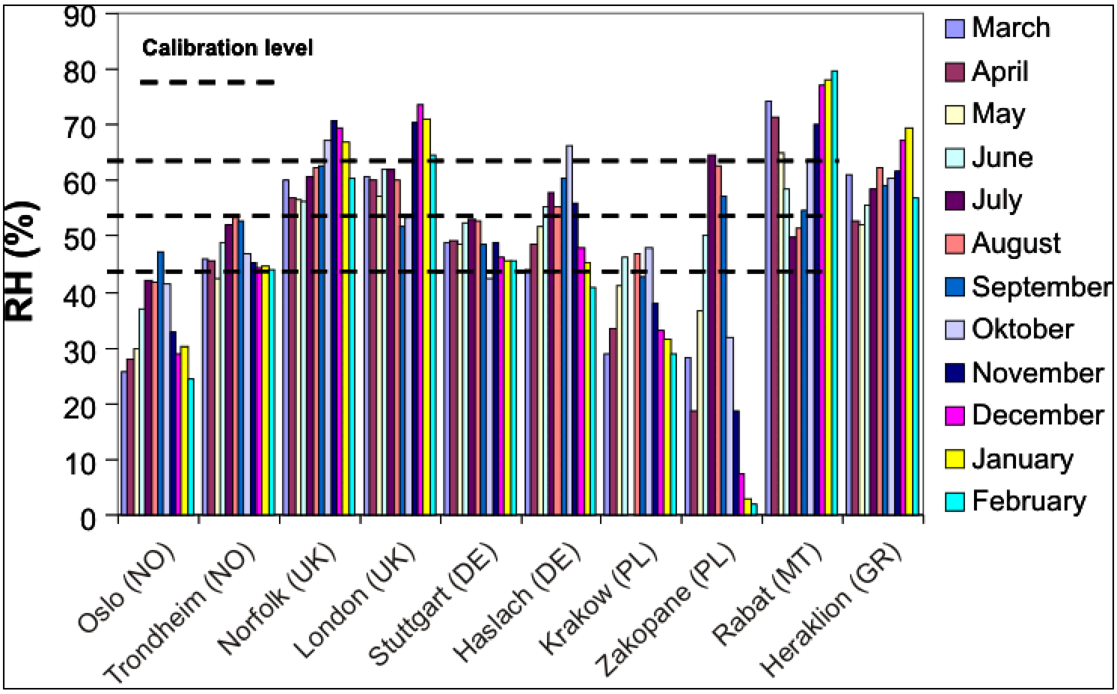


Figure 2.36: Indoors relative humidity in the10 museums depending on season from March 2004-February 2005.

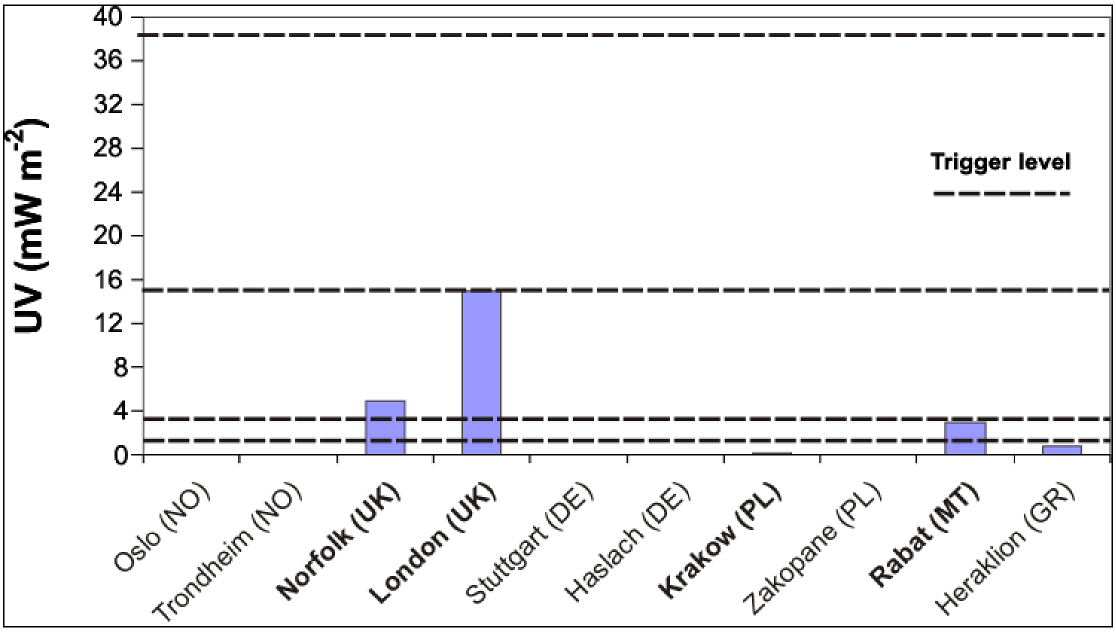


Figure 2.37: Indoor yearly mean UV, 12 o'clock noon.

Figure 2.38 shows the first 1 month and 3 months exposures of the EWO-G dosimeter for all the sites. Figure 2.39 to Figure 2.41 show the effect on the EWO-G dosimeter at the 10 sites.

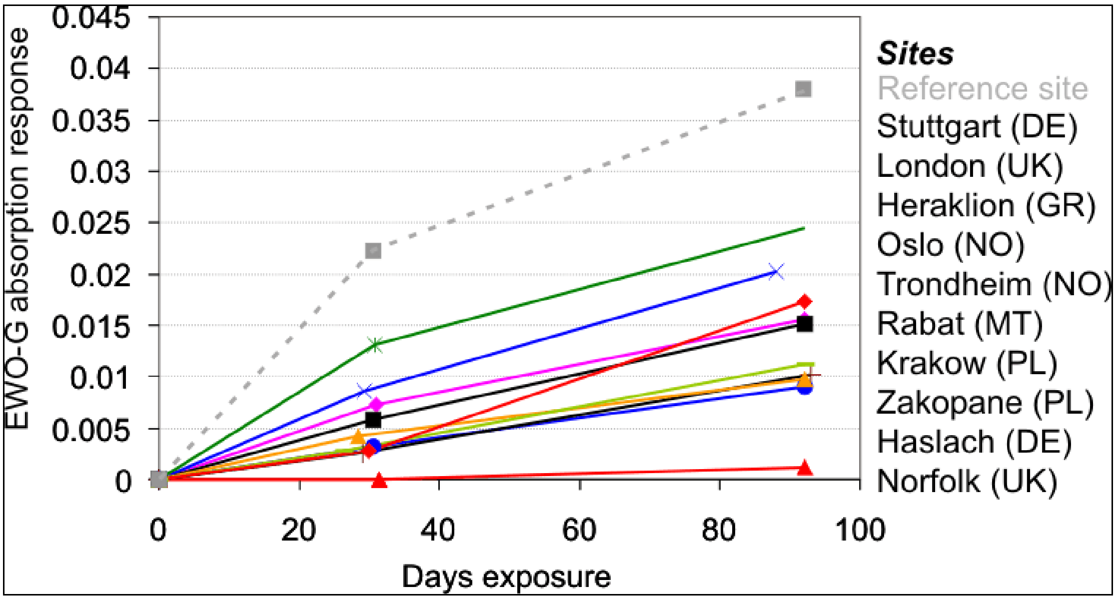


Figure 2.38: The dosimeter response in the first 1 month and 3 months exposures for all the sites.

2.4.3 Results from the EWO-G dosimeter effect

The best exposure time for the EWO-G dosimeter was decided to be three months as the effect is relatively linear with time up to 3 months, with some saturation only reached for the most exposed sites. (Site 11 was the NILU lab, which was used as a reference to the museums) This made it possible to perform statistical calibration with a linear equation for the 3 months exposures. 3 months, one season, was evaluated to be sufficient exposure time to get representative integrated values for the dose effect. Figure 2.39 shows the effects on shielded and unshielded EWO-G samples for one month exposures.

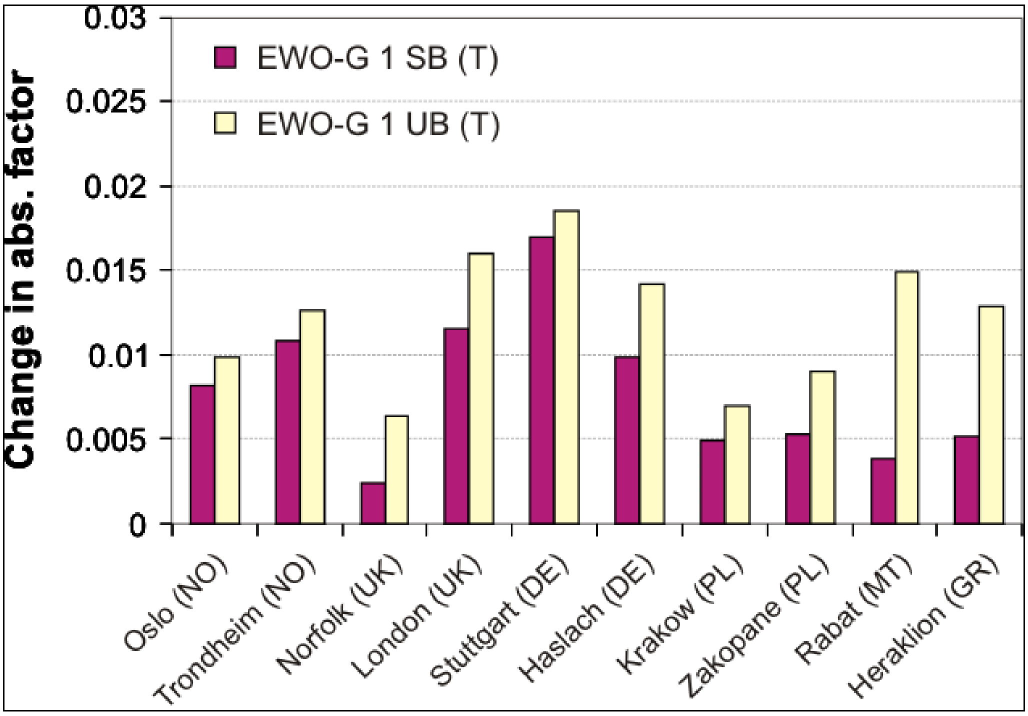


Figure 2.39: Responses on shielded (SB) and unshielded (UB) EWO-G dosimeters exposed at site B, for one month (May 2004).

From the statistical analysis it was observed that the higher response on the unshielded samples was caused by larger effect of O_3, as measured by the passive samplers, and by UV light. It was reasoned that the very reactive O_3 deposited on the shields so that O_3 deposition on the dosimeter chips decreased. UV light would not reach the dosimeter chips under the shields. Figure 2.40 shows the mean response of the EWO-G unshielded dosimeters for the A (outdoors), B (indoors) and C (showcase) locations at the 10 sites, for the four 3 months exposures, during the year of the field test. Based on the analysis from the field test results it was decided to use unshielded dosimeters as these responded more to the total environment, which also influences museum objects.

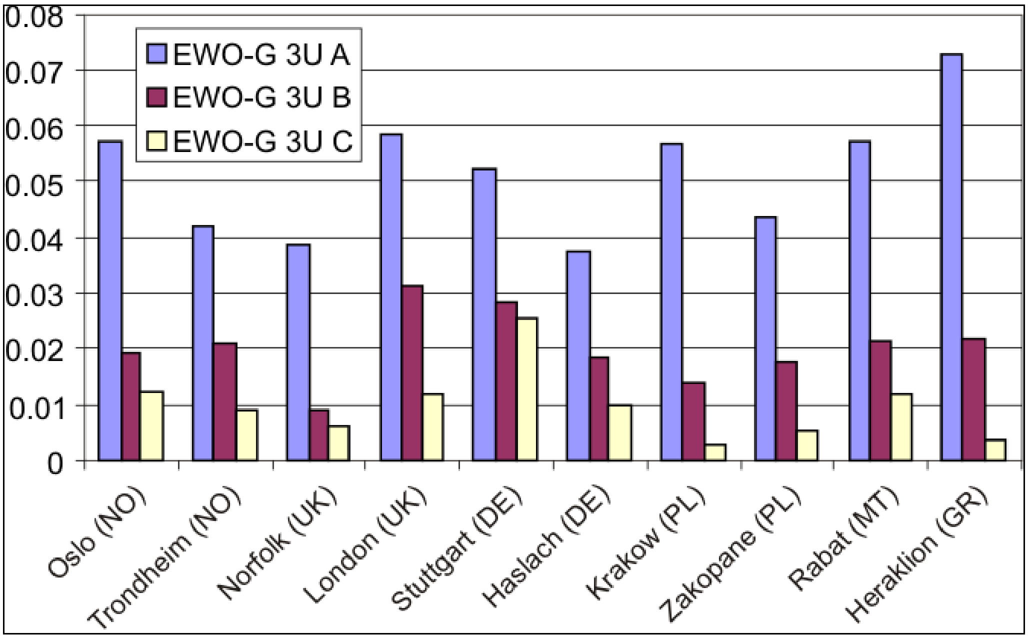


Figure 2.40: Mean response of four 3 months exposures for the EWO-G unshielded dosimeters for the A (outdoors), B (exhibition area) and C (showcase) locations at the 10 museum test sites.

2.4.4 Correlation of environmental measurements and the dosimeter effect

Mean 3 monthly values for the environmental parameter measurements at site B were correlated with the 3 monthly response values measured on the EWO-G dosimeters using multivariate regression analysis. This analysis gave the calibration Equation 1 with all effects significant on a 95 % level (two sided).

$$\text{EWO-G effect(x1000)} = 0.75NO_2 + 1.34O_3 + 0.51T + 0.35UV$$

with NO_2 and O_3 as ppb, T as ^oC and UV as mW m^{-2}. The correlation of predicted values from the equation with measured values for the EWO-G effect at site B is shown on Figure 2.41.

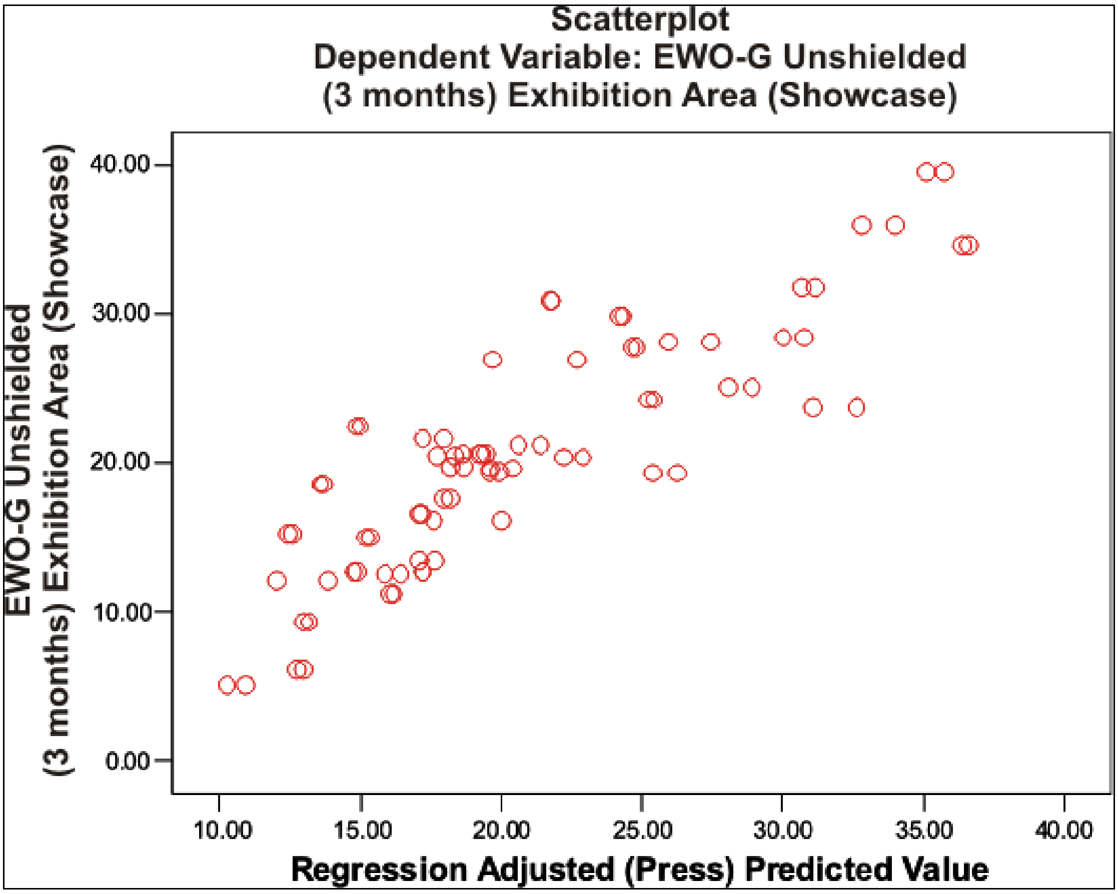


Figure 2.41: Correlation of predicted values from the calibration equation with measured values for the EWO-G effect at site B.

2.4.5 Results from Field testing of the EWO-S dosimeters

The EWO-S dosimeters for NO_2, O_3 and SO_2 were exposed in the field test during selected months as a part of the research effort. This was very useful for evaluation of responses in “real” exposures outside the controlled laboratory setting. Figure 2.42 shows a correlation of the monthly results of the EWO-S dosimeter for NO_2 together with the results of the passive sampler.

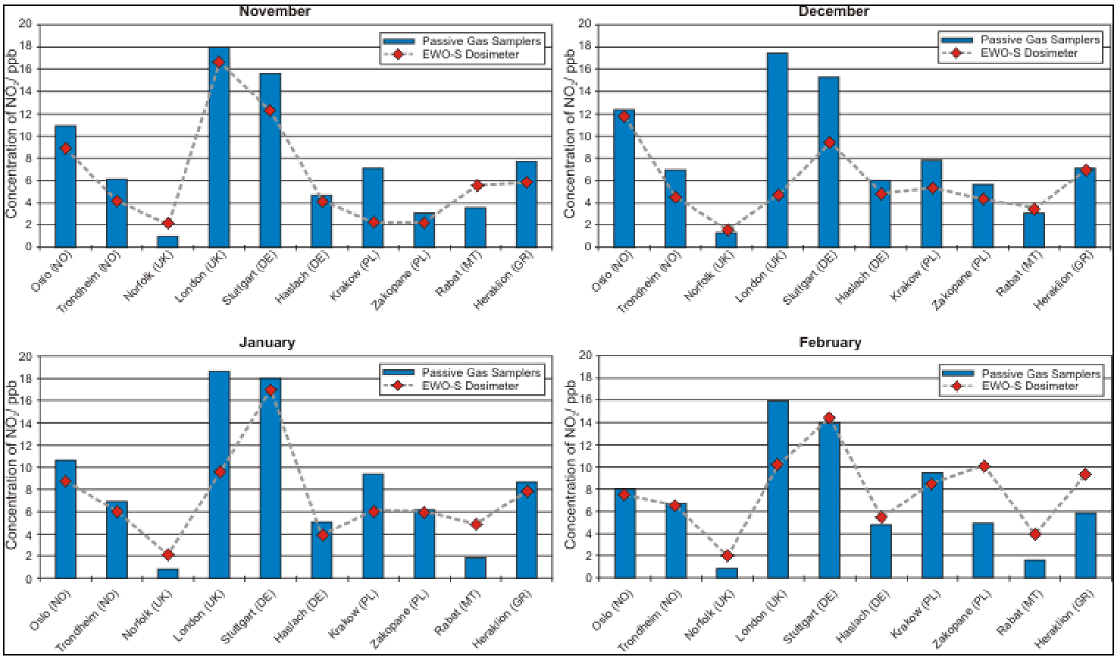


Figure 2.42: Comparison between the results of the passive gas samplers for NO_2 – blue bars – and the results of the EWO-S dosimeter sensitive for NO_2 – red rhombus – at all exposure sites from November 2004 till February 2005.

2.4.6 Results from the exposed silk samples

"The silk samples were analysed by Historic Royal Palaces using size exclusion chromatography to determine molecular weight distribution (MW as a measure of degradation. The amount of degradation was then correlated to the measured environmental data, and ultimately to the dosimeter response, to look for similarity of trends. The greatest amount of change in silk was measured for samples exposed externally at the test sites. The MW of external silk decreased significantly compared to silk samples exposed in galleries and showcases. In some cases, the showcase also reduced deterioration very slightly. In each country studied, the urban sites showed more silk deterioration than the rural sites in the same country. Figure 2.43 shows the greater deterioration experienced by silk samples exposed outdoors. Since light is known to be a major deterioration factor, the molecular weight of samples was compared between exposed and shielded silk. A general trend was discovered toward less deterioration in shielded samples across the field test, shown by Figure 2.44.

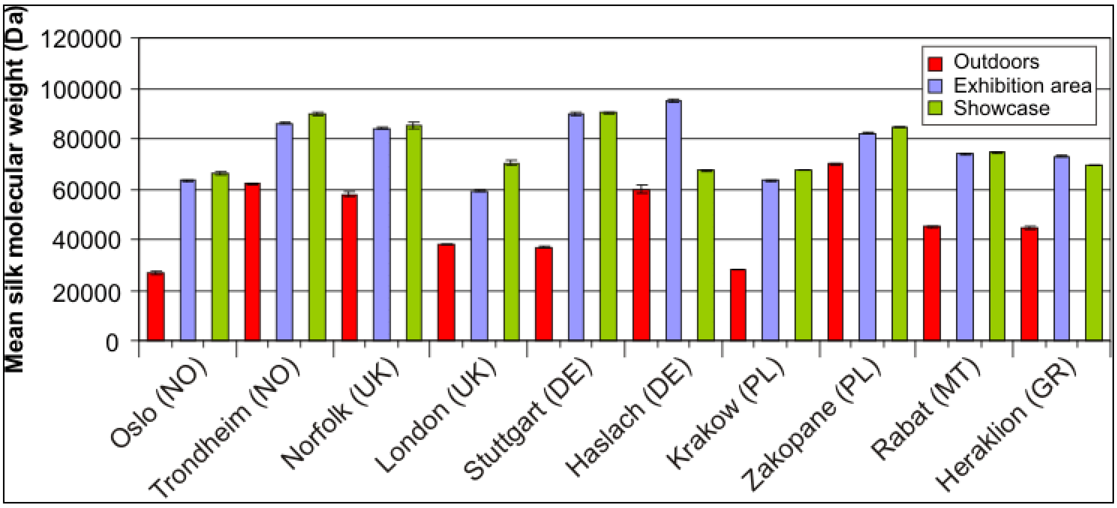


Figure 2.43: Deterioration of silk samples exposed outdoor at the 10 museum test sites

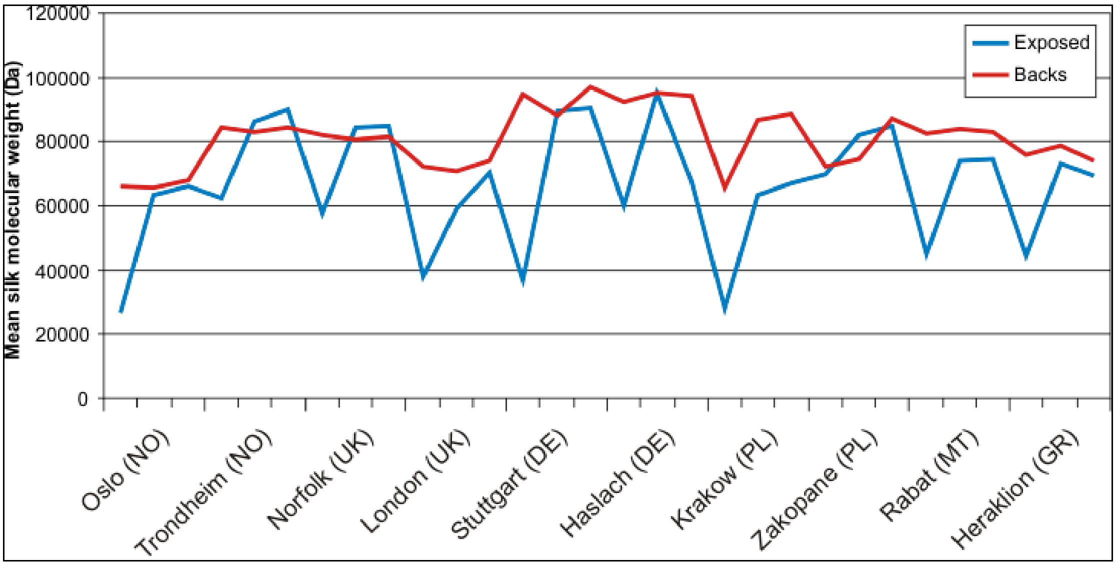


Figure 2.44: Deterioration of shielded silk samples at the 10 museum test sites

The silk data was also examined in conjunction with the EWO-G dosimeter response for each site, and it was found that the best correlation occurred between shielded external silk and the EWO-G dosimeter (Figure 2.45). The silk exposed indoors in galleries and showcases generally deteriorated too little over the course of only one year for significant correlation with the dosimeters (which are designed to detect aggressive environments prior to significant change in organic objects). Statistical data path analysis suggested that NO_2 and light particularly affected silk outdoors."

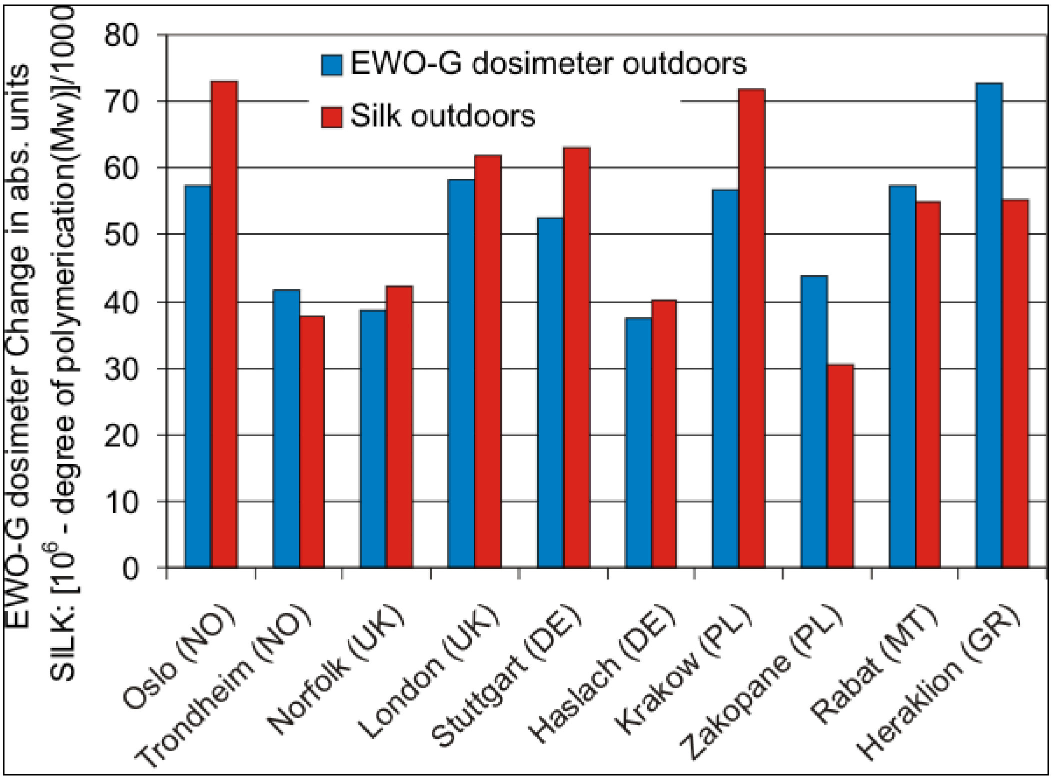


Figure 2.45: Correlation between shielded external silk and the EWO-G dosimeter.

References see Chapter 6.7.

2.5 The use of Indoor/outdoor modelling for cultural heritage sites

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The use of microenvironmental indoor/outdoor models in conjunction with monitoring data can provide valuable information on the deterioration of materials susceptible to pollution, in exhibits in museums and historical archives.

The average indoor NO_2 and O_3 concentrations measured during the MASTER project were modelled using the IMPACT model. The IMPACT model is a web based software tool designed to predict indoor concentration of the most damaging gaseous pollutants found inside museums and historical archives (Figure 2.46) The model is a Java Applet accessible via Internet web browsers, such as Internet Explorer or Netscape (http://www.ucl.ac.uk/sustainableheritage/impact/) and can be used without special license. The IMPACT model was already developed as part of the IMPACT Project ("Innovative Modelling of Museum Pollution and Conservation Thresholds, EVK4-CT-2000-00031) and it was decided to test this model with the results from the MASTER field test data (Grøntoft et al., 2005).

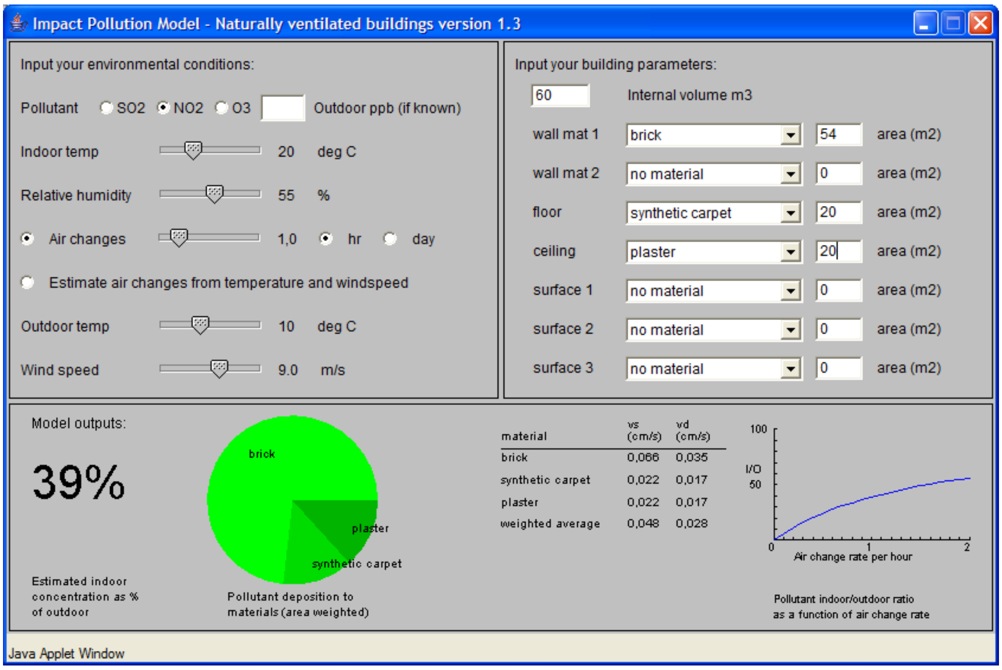

Figure 2.46: The web interface for the IMPACT project. - Naturally ventilated buildings model.

The IMPACT model can be used to calculate the indoor average concentration of NO_2, O_3 and SO_2. The behaviour of these gaseous pollutants is governed by a mass balance equation of the form:

$$\frac{dC}{dt} = P\lambda C_{out}(t) - \lambda C_{in}(t) - v_d \frac{A}{V} C_{in}(t) - kC_{in}(t) + S(t)$$

In the above equation, the first term on the right hand side represents the portion of the outdoor concentration that enters the indoor environment, the second, third and fourth term represent pollutant losses due to exfiltration deposition and chemical reactions respectively and the last term represents the pollutant production from indoor sources.

However, the IMPACT model is an equilibrium model. The model assumes that there are no indoor sources of NO_2, O_3 and SO_2 and that pollutants are chemical inert. Moreover measured values for net deposition to indoor surfaces are used, thus avoiding the problem of desorption of pollutants from the materials. The model takes into account the influence of temperature and relative humidity on deposition velocity. Thus the IMPACT model calculates the indoor average concentration of NO_2, O_3 and SO_2 by solving a deposition based mass balance equation:

$$\frac{C_i}{C_0} = \frac{\lambda}{\lambda + v_d (A/V)}$$

where C_i and C_0 are the pollutant concentration indoors and outdoors, λ is the overall building ventilation rate (air exchange rate, hr^{-1}), A/V is the surface area to volume ratio of interior ((m^2)/ (m^3)) and v_d is the deposition velocity (m hr^{-1} or cm s^{-1}), an expression of how well a particular surface takes up a particular pollutant gas. In the IMPACT model there is no dependence of concentration on time therefore mean concentrations for long periods of time can be calculated with the model. In our case study, long time average concentrations are more important when we want to estimate deposition of pollutants to materials related to the deterioration of the art works. Short term elevated concentrations might cause problem to humans and be a threat to human health, but do not contribute much in the deterioration of art works exhibited in museums, historic buildings and archives.

Since indoor emissions are considered to be zero, pollutants can be transported indoor only by infiltration from the outdoor environment through open doors and windows and through cracks of the building shell. The study area is modelled as a rectangular box, which communicates with the outdoor environment via airflow. The whole room is treated as a single well-mixed zone and the concentrations of the gaseous pollutants are assumed to be uniform throughout the room. Pollutants are removed by exfiltration and deposition on indoor surfaces. Deposition values for different materials used in the model have been estimated from intensive laboratory measurements as part of the IMPACT project. The user can choose the material covering indoor surfaces such as walls, ceiling, floor and other large objects (e.g. showcases) found inside the room. Table 2.5.1 presents the list of materials that are available in the model.

Table 2.5.1: List of materials for indoor surfaces, used in the IMPACT model.

Brick	Glass	Plastic	Wood, oiled
Cardboard	Granite	Sandstone, calcareous	Wood, hard
Chipboard	Limestone	Sandstone, silicate	Wood, painted
Cloth	Marble	Slate	Wood, soft
Carbon cloth	Metal	Synthetic carpet	Wool textile
Concrete, coarse	Paintings	Synthetic floor	Wood, oiled
Concrete, fine	Plaster	Wallpaper	

The air exchange rate can be entered directly in air exchanges per hour or air exchanges per day, the latter being more suitable for museum display cases, or roughly estimated by the difference in temperature between the inside and outside of the building and the external wind speed. The model can be applied both in naturally ventilated and mechanically ventilated buildings. In a mechanically ventilated building, the air entering the room is a mixture of fresh air from outside and re-circulated indoor air that has been purified by a combination of mechanical filters. The user is asked to give values regarding the air intake, the filter efficiency and the portion of fresh air to re-circulated air entering the indoor environment. In equilibrium conditions the mass balance equation used in the model is (EU project IMPACT, 2004):

$$\frac{C_i}{C_o} = \left(\frac{(1-\eta) f_{ox} + f_{oi}}{f_{io} + v_d A + f_{ix}\eta} \right)$$

where f_{ox} is the fresh air intake to the mechanical ventilation system, f_{ix} is the quantity of air, which is re-circulated, f_{io} is the exfiltration/mechanical exhaust from the building, f_{oi} is the natural infiltration , η is the filter efficiency, A is the surface area of the room and V is the total room volume.

A schematic representation of infiltration conditions in the case of mechanically ventilated buildings is displayed in figure Figure 2.47. In the limit of the mechanical airflows being zero, the model gives exactly the same answers as the equation used for naturally ventilated buildings.

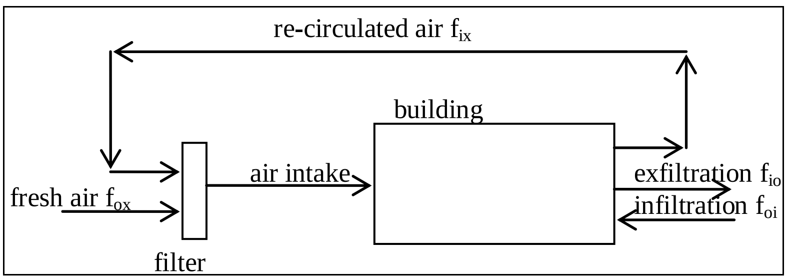

Figure 2.47: A schematic representation of infiltration conditions in the case of mechanically ventilated buildings.

A semi-empirical algorithm was developed in order to model the influence of temperature and relative humidity on deposition velocity. The algorithm was applied in combination with laboratory measurements in selected values of temperature and relative humidity. The deposition velocity for temperature and humidity range 0-35^{o}C and 0-100% accordingly was found by interpolation between the selected values. The user of the model can introduce the mean temperature and relative humidity for the selected modelled period.

Evaluation of the IMPACT model

The evaluation of the IMPACT model has been performed using the experimental data collected from passive samplers at the ten different test sites between March 2004 and March 2005 (Grøntoft et al. 2005) for the naturally ventilated museums. The annual experimental campaign included indoor/outdoor measurements of NO_2, SO_2 and O_3 mean monthly concentrations and continuous measurements of temperature and relative humidity. Two passive samplers were used for every different gas in order to avoid mistakes. All rooms were considered to be rectangular. The indoor surfaces and materials provided by the museums have been used as input to the model and several different ventilation scenarios have been evaluated considering their impact on the indoor concentration of the oxidising pollutants. In cases where the material was not in the IMPACT list of materials that can be inserted in the model, the material showing the closest value of deposition velocity was selected. Ventilation rate which is a crucial parameter for the model was roughly estimated by the ratio $\lambda = C_{in} / (C_{out} - C_{in})$ where NO_2 mean monthly values were used. NO_2 was selected because it is less reactive than ozone and therefore its deposition rate on surfaces is lower than the deposition rate of ozone. In cases where $\lambda>5$ or $\lambda<0$ the air exchange rate was set to 5 and 0.1 accordingly. These extreme values appear when the indoor concentration is very close or higher than the outdoor concentration. These cases represent 20% of the total cases investigated and are almost equally shared between the Oslo, London and Haslach Museum.

The model was applied for all naturally ventilated museums. Experimental data of temperature, relative humidity and outdoor concentration of NO_2 and O_3 along with the calculated values of λ were used as input data for the model. Indoor concentration values of NO_2 and O_3 were computed. No modelling attempts have been made for SO_2, since indoor concentrations most of the times were below the detection limit of the dosimeters. The results of the model were averaged for two different periods: the "winter period" (October-March) and the "summer period" (April-September). The reason was the differences observed in temperature, relative humidity and outdoor concentration between these two periods.

Model runs have been performed separately for each month, each 6-month period and for the whole year of field measurements. Runs have been made using the actual environmental conditions, interior surfaces and objects and the estimated λ. The model results for NO_2 showed good agreement with measured concentrations of NO_2, especially for the summer period. On the other hand the IMPACT model over predicts the indoor ozone concentration in all the cases studied. More specifically the agreement between measured and modelled data for NO_2 is very good both for the summer and winter periods, whereas for O_3 the best agreement was observed for the summer period. However the model performance experience systematic errors, especially in the case of modelling O_3 concentrations, and can be significantly improved. Specifically the model agreement between the predicted and measured NO_2 concentration during the 12 month measurement period was found to be better for the Tower of London and almost perfect for the Wignacourt museum. Considering the O_3 predicted concentrations the best fit of modelled to measured data was found for the Haslach museum (Correlation coefficient 0.86). Moreover the systematic errors produced by the model were found significantly larger than the unsystematic ones for all the museums and especially for the calculation of O_3 concentration. The model tends to overestimate the indoor concentration of both oxidizing gaseous pollutants. For the NO_2 better results were obtained for the winter rather than for the summer period. The above remark applies also to the model performance in predicting O_3 indoor concentrations. The equilibrium chemical reaction that links NO_2 and O_3 in the atmosphere is:

$$NO + O_3 \leftrightarrow NO_2 + O_2$$

The forward reaction is favoured by high O_3 concentration whereas the reverse one is driven by sunlight. During the summer O_3 concentration outdoors is increased due to the increased sunlight. Therefore higher concentrations of O_3 are observed indoors during the summer than in the winter period and as a result NO_2 is produced in the indoor environment according to the above reaction. Moreover the museums are designed to block sunlight out form the interior where collections are exhibited and thus produced NO_2 is not destroyed by the above reaction. Consequently indoor to outdoor NO_2 concentration ratios greater than 1 have been observed inside museums during the summer (Camuffo et al., 2001). The measurement data in this case study indicated that NO_2 was indeed produced indoors during the summer period for some of the museums. For example during May the concentration of NO_2 inside the Trøndelag Folk Museum (Trondheim, Norway), Haus der Geschichte Baden-Württtemberg (Stuttgart, Germany), Historical Museum (Heraklion, Greece) museums and the Tower of London (London, UK) was higher than the outdoor.

In order to examine the parameters responsible for the systematic error observed by the model and find the mechanisms that should be included in an improved version, runs have been performed using variable λ values, no objects inside the room and double surface areas. The model performance was either slightly improved or worsened for the 6 month periods and each different museum. The examination of the results provided insight to the parameters influencing indoor air quality in each museum and specified the possible improvements of the model. More specifically, by increasing the surface area to double size we increased the deposition potential of pollutants and therefore found lower concentrations in the interior of the museums. The mean decrease of O_3 and NO_2 modelled concentrations was 23.1 % and 12.7 %, respectively. Moreover, a stronger decrease of O_3 and NO_2 were observed in the Blickling Hall, Haslach and Wignacourt museums, which have smaller volumes than the others. Nevertheless the model performance was not significantly improved.

In addition, the removal of objects from the room was modelled in the context of examining the effect of deposition on the indoor concentration of pollutants in the museums. The model results in this case were not considerably altered. In fact the overall model performance for the winter, summer and annual periods was slightly worsened. This remark was expected as the removal rate of pollutants from the indoor air by deposition/adsorption to surfaces was reduced by removing surfaces.

The model performance considering the indoor NO_2 concentration estimation was even worsened for air exchange rates one order of magnitude less than the estimated ones. On the other hand the predicted indoor ozone concentrations were closer to the observed values. However λ values close to 0.1 are useful only for modelling scenarios and cannot be observed in naturally ventilated museums.

Measured and modelled concentrations and results considering the model performance parameters are presented in Table 2.5.2–Table 2.5.4.

Table 2.5.2: Measured and modelled NO_2 and O_3 concentrations for the winter period.

Museum	NO_2 Concentration (ppb)			O_3 Concentration (ppb)		
	Observed	Modelled (λ)	Modelled (λ/10)	Observed	Modelled (λ)	Modelled (λ/10)
Oslo	10.4	15.7	6	1.2	5.3	1
Blickling Hall	1.2	1.7	1	1.1	6.0	4
Tower of London	17.9	16.8	6	2.9	7.3	7
Haslach	5.5	6.3	2	2.0	6.0	2
Krakow	8.9	11.8	4	0.7	2.8	2
Zakopane	4.7	9.3	4	1.7	7.7	3
Wignacourt	3.0	3.0	1	3.4	12.2	2
Average values	7.4	9.2	3.4	1.8	6.8	3

Table 2.5.3: Measured and modelled NO_2 and O_3 concentrations for the summer period.

Museum	NO_2 Concentration (ppb)			O_3 Concentration (ppb)		
	Observed	Modelled (λ)	Modelled (λ/10)	Observed	Modelled (λ)	Modelled (λ/10)
Oslo	8.5	8.7	7	0.8	13.8	5
Blickling Hall	1.7	2.0	1	1.0	10.8	3
Tower of London	16.0	10.2	4	4.5	9.0	4
Haslach	4.9	2.3	1	7.2	11.2	3
Krakow	6.0	7.0	2	0.6	6.2	2
Zakopane	2.9	3.0	2	2.7	8.7	3
Wignacourt	3.1	3.0	1	3.1	14.5	2
Average values	6.1	5.2	2.6	2.8	10.6	3.1

Table 2.5.4: Measured and modelled NO_2 and O_3 concentrations for the whole period.

Museum	NO_2 Concentration (ppb)			O_3 Concentration (ppb)		
	Observed	Modelled (λ)	Modelled (λ/10)	Observed	Modelled (λ)	Modelled (λ/10)
Oslo	9.5	12.2	7	1.0	9.6	3
Blickling Hall	1.5	1.8	1	1.1	8.2	3
Tower of London	17.0	13.5	5	3.7	8.2	4
Haslach	5.2	4.3	2	4.6	8.6	3
Krakow	7.4	9.4	3	0.6	4.5	2
Zakopane	3.8	6.2	3	2.2	8.2	3
Wignacourt	3.0	3.0	1	3.2	13.3	2
Average values	6.8	7.2	2.5	2.3	8.6	2.9

Finally, in order to find the optimal λ for which the model performance, under the present assumptions in the model, gave the best estimates of the indoor concentrations of the oxidizing gases a reverse modelling approach was used. For NO_2 we found that an accurate measure of the ventilation rate, the exchange of air between rooms of the museum and probably the inclusion of homogeneous chemical reactions in the model (evidence of indoor NO_2 production from the field data in some museums) can increase the model performance whereas the predicted concentrations of O_3 for most of the museums were overestimated even at ventilation rates equal to 0.1 air exchanges per hour. This indicates that ozone deposits faster in indoor surfaces and also that lower penetration from the outdoor environment should be considered in the model. More specifically, the air exchange in museums occurs mostly through cracks in the building shell, since the windows are closed during most of the day. Nazaroff and Liu (2001) reported that ozone shows very high reaction probability (γ) for cracks, with crack height less than 0.5 mm. Ozone deposits strongly in the surfaces of the cracks and it does not penetrate in the indoor environment. Moreover a portion of the air entering from outdoors is distributed in other rooms, since in many cases the space studied communicates via airflow with other rooms in the building. Ozone entering from outdoor is transferred in these rooms and it is deposited on the surfaces (floor, walls, ceiling and exhibits) of these rooms. The air exchange between different rooms is not considered in the model.

A reworked version the IMPACT model, "the MASTER model", including photolysis and homogeneous NO_x–O_3 chemistry was formulated and tested with experimental data in the MASTER project.

The MASTER model

Simple indoor to outdoor (I/O) models without homogeneous chemistry cannot completely explain the I/O levels of NO_2. The I/O ratio of NO_2 depends on a number of factors relating to different mechanisms for and different rates of the production and consumption of NO_2 indoors and outdoors. The important factors are the photolysis rate of NO_2 outdoors as compared to indoors, the emissions of NO_2 and other gases that are important for the homogeneous chemistry of NO_2, and the particular building characteristics. The inclusion of photolysis and homogeneous NO_x–O_3 chemistry is, when there are no indoor NO_2 emissions, needed to explain observed NO_2 I/O- ratios > 1.

Two steady state models that explain NO_2 I/O ratios were developed in the MASTER project. Weschler et al. (1994) shows that NO and O_3 do not usually coexist in a steady state. Rather, due to the rapid reaction of NO with O_3, only the surplus gas of the two will be present at any one time. The MASTER models do not describe the dynamic reaction between the NO_x and O_3 species. For that purpose numerical models would be needed. The models presented here simplifies the dynamic complexity of the homogeneous NO_x–O_3 chemistry for the purpose of improving simple box models. Model 1 should be used with continuous data with a time resolution sufficiently high, e.g. hourly measurements, to describe the dynamic changes in the outdoor concentrations. The simplified Model 2 should be used with measurements of long time, e.g. monthly, mean outdoor values. Model 2 is a semi-empirical model that describes the mean reduced amount of NO and O_3 reacting indoors with a factor, x, that was determined by fitting of the model to the MASTER field test data. The purpose of Model 2 is to add the effect of outdoor photolysis to simple steady state I/O model for NO_2, such as the IMPACT model (IMPACT web site, 2006) that can calculate integrated indoor gas doses. The two models explain why NO_2 indoors can be higher than outdoors when there are no indoor emissions of NO_2. Model 2 compares successfully with the field data. The models are here presented "ready for use" with needed values for input parameters.

The expression for **Model 1** is:

$$\mathbf{NO(i)} = \frac{-\mathbf{B} + \left(\mathbf{B}^2 - 4\mathbf{AC}\right)^{0.5}}{2\mathbf{A}}$$

with:

$$\mathbf{A} = \mathbf{k}\lambda$$

$$\mathbf{B} = \lambda^2 + \mathbf{k}\lambda\mathbf{O}_3(\mathbf{o}) + \lambda\mathbf{v_d}(\mathbf{O}_3)\frac{\mathbf{A}}{\mathbf{V}} - \lambda\left(\frac{\mathbf{jNO}_2(\mathbf{o}) + \mathbf{e}}{\mathbf{O}_3(\mathbf{o})}\right)$$

$$\mathbf{C} = \left(\lambda^2 + \lambda\mathbf{v_d}(\mathbf{O}_3)\frac{\mathbf{A}}{\mathbf{V}}\right)\left(\frac{\mathbf{jNO}_2(\mathbf{o}) + \mathbf{e}}{\mathbf{kO}_3(\mathbf{o})}\right)$$

If outdoor NO concentrations are used as input instead of the emission rate, e, of NO in the expression for Model 1, then:

$$\frac{\mathbf{jNO}_2(\mathbf{o}) + \mathbf{e}}{\mathbf{kO}_3(\mathbf{o})} = \mathbf{NO(o)}$$

in the model solutions, last term of expressions B and C.
The expression for **Model 2** is:

$$\frac{\mathbf{NO}_2(\mathbf{i})}{\mathbf{NO}_2(\mathbf{o})} = \frac{\lambda + \mathbf{x}^2\left(\mathbf{j} + \frac{\mathbf{e}}{\mathbf{NO}_2(\mathbf{o})}\right)}{\lambda + \frac{\mathbf{A}}{\mathbf{V}}\mathbf{v_d}(\mathbf{NO}_2)}$$

If outdoor NO concentrations are used as input instead of the emission rate, e, of NO the expression for Model 2 is:

$$\frac{\mathbf{NO}_2(\mathbf{i})}{\mathbf{NO}_2(\mathbf{o})} = \frac{\lambda + [\mathbf{x}^2\mathbf{O}_3(\mathbf{o})\mathbf{NO}(\mathbf{o})]/\mathbf{NO}_2(\mathbf{o})}{\lambda + \frac{\mathbf{A}}{\mathbf{V}}\mathbf{v_d}(\mathbf{NO}_2)}$$

For both models:

$NO_2(i)$ = the indoor concentration of NO_2 (ppb)
$NO_2(o)$ = the outdoor concentration of NO_2 (ppb)
$O_3(o)$ = the outdoor concentration of O_3 (ppb)
$NO(o)$ = the outdoor concentration of NO (ppb)
$v_d(NO_2)$ = the indoor mean deposition velocity of NO_2 ($m\ s^{-1}$)
$v_d(O_3)$ = the indoor mean deposition velocity of O_3 ($m\ s^{-1}$)
k = $4.43*10^{-4}$ $ppb^{-1}\ s^{-1}$ = the rate constant for the reaction of O_3 with NO
λ = the air exchange rate (s^{-1})
j = the photolysis rate constant for NO_2 (s^{-1})
e = the outdoor emission rate of NO ($ppb\ s^{-1}$)
A = the room surface area (m^2)
V = the room volume (m^3)

In Model 2, A = geometrical areas of the room, x = 0.5 and $v_d(NO_2) \approx 0.003\ m\ s^{-1}$, equal to 6 * mean $v_d(NO_2)$ from laboratory measurements, should be used, - as was found from the fitting of the model to the field test data. The latitude dependent mean monthly photolysis rate, j, (Simpson et al., 2003) to used in Models 1 and 2 can be read from Figure 2.49.

Figure 2.48: Text: Tower of London, England. A relatively open structure gives high indoor to outdoor rations of pollutants.

Indoors NO_2 and SO_2 are relatively easy to predict and models like the IMPACT model give quite good results. O_3 is a very reactive gas and good modelling results require thorough consideration of all supply and loss factors in each case. One should be aware of possible biases in relatively simple models such as the IMPACT model.

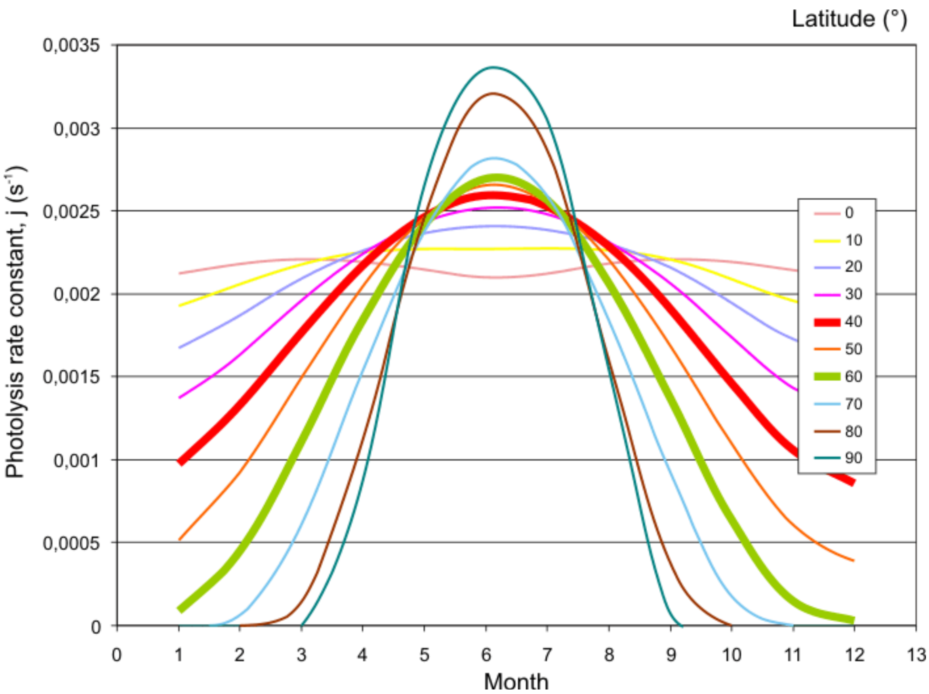

Figure 2.49: Mean monthly photolytic rate constants for splitting of the NO_2 molecule dependent on month and latitude. 50 % cloud cover.

The fit of Model 2 to the field test results using multivariate regression is shown in Figure 2.50 for the Stuttgart site. Parameter values obtained from the fitting were in the ranges expected. For better validation of the model much more detailed analysis of room characteristics would however be needed.

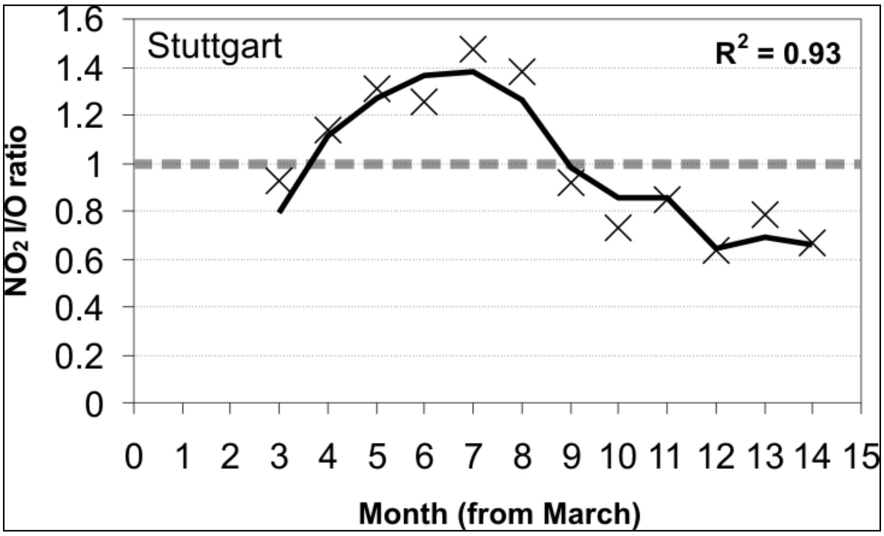

Figure 2.50: Fit of the MASTER Model 2, including photolysis and homogeneous chemistry to Indoor/Outdoor ratios of NO_2 for the Stuttgart museum site.

The indoor O_3 + NO reaction gives increased indoor exposure to NO_2. Increased NO_2 concentrations by itself increase materials decay. However the O_3 + NO reaction decreases the O_3 concentration equally much as it increases the NO_2 concentration. The total effect on museum materials of the O_3 + NO reaction included in Model 1 and 2 would therefore depend on the relative vulnerability of materials to the two gases.

The utility of an "improved IMPACT model"

In addition to the inclusion of homogeneous chemical reactions of pollutants the inclusion of a penetration coefficient for ozone would enhance the predictive capabilities of the model. Such a model can be used for evaluating different ventilation scenarios and ventilation system designs and for estimating the air exchange rate that prevents indoor concentration of O_3 and other oxidizing pollutants to exceed acceptable concentrations for preservation. Moreover such a model could provide decision makers with valuable information considering the emission abatement strategies in the areas in the vicinity of the cultural heritages sites, museums and historical archives.

References see Chapter 6.8

2.6 The End-user involvement in the MASTER project

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An important part of the project development was the explicit inclusion of consultation with end-users. The MASTER project continually sought out feedback from expert end-users about the development of the dosimeters at key points in the project.

Since the MASTER project was developing products for a specific community, end-user feedback was vital. Incorporating the end-user process into the framework of the project proved to be highly influential, useful and challenging.

1. Developing end-user workshops

Although the outcomes of the workshops are never known in advance, they do require considerable preparation to ensure that maximum use is made of the delegates and time. Preparatory meetings with facilitators are essential to determine the kind of information that is sought after, and to ensure the smooth running of the workshop.

The workshop aims and the roles of all in attendance should be explicitly stated. This allows the project team to best decide how they wish to present the information and how they wish the end-users to respond, as well as the most appropriate venues to meet such aims. The nature of end-user workshops is different for a number of reasons, particularly because they might be related to different stages of a project. Determining the best way to extract information from a group of experts in a short space of time will require consideration and clear communication between the project team and the facilitator.

If the value of the workshops is to benefit the project, the project needs to be adaptable enough to change. The feedback and outcomes cannot, nor should, be known. As a result, the subsequent stages of the project only benefit from recommendations if there is the potential to adapt the project to meet these aims. Recommendations and feedback may reveal unexpected research directions, which need to be considered if the workshops are to have any influence or value.

'Figure 2.51: Partner and End user representatives in the MASTER project. The End Users give input to project development and evaluation all through the project.

2. The Workshops

The MASTER project had three workshops: one at the beginning of the project, when the project was at a conceptual, information-gathering stage, one in the middle of the project after the field test had been completed and the work packages were producing results, and one at the end of the project when all of the work had been completed and assembled.

2.1 First End-user workshop

The first workshop took place over two days at the National Museum in Krakow, Poland with nine end-users and a facilitator (Table 2.6.1). The end-users invited to attend the workshop were chosen for several reasons, including their expertise in monitoring and preventive conservation strategy, and their collective ability to represent different parts of Europe and different kinds of institution. The introduction of a facilitator was thought necessary to ensure that the discussion was independent of the project team. The absence of the project team in discussion, and the external guidance, meant that critical information or recommendations that are difficult to achieve would be more likely to arise.

Table 2.6.1: List of the end-users and facilitator present at the end-user workshop in Krakow.

Group A (strategy to dosimeter)	**Group B (dosimeter to strategy)**
Names of end-users (professional affiliations at time of workshop)	
Sarah Staniforth (National Trust, UK) **Monika Fjaested** (National Heritage Board, Sweden) **Jørgen Wadum** (Chair of ICOM-CC and Royal Cabinet of Paintings Mauritshuis, Holland) **Astrid Brandt-Grau** (Département des restaurateurs du patrimoine, Institut national du patrimoine, France)	**Marta Jaro** (Hungarian National Museum, Hungary) **Dorte Poulsen** (School of Conservation, Danish Academy of Fine Arts, Denmark) **David Thickett** (English Heritage, UK) **Barry Knight** (British Library, UK) **Paula Menino Homen** (Universidade do Porto, Portugal)
Facilitator: Jonathan Ashley-Smith	

The project was in a very early stage, so there was little technical information that could be given to the end-users. However, this meant that the end-users had an opportunity to discuss what they would like to see without being limited by what already existed. It also meant that the project team could think about the direction of future development without having to change existing work.

The workshop consisted of presentations about the project and dosimetry in general, and a question and answer session before the end-users discussed topics related to the project. The end-users were split into two groups, one to discuss dosimeters used in preventive conservation strategy and one to discuss preventive conservation strategy and information needs. Each group was given prepared questions to discuss. The intention was that discussion in the groups would approach the same subject from different starting points. This provided perspectives on how monitoring and preventive conservation strategy best fit together, as well as information on monitoring and strategy in general. Both groups were given questions at each stage of the workshop (Figure 2.52) for direction but the discussion was encouraged to flow freely. This was seen as an opportunity to gain fresh perspectives at an appropriate time, so there was an intention not to ‘prime’ the end-users with the project team’s expectations or opinions. The discussion had different stages that incrementally brought the topics closer together until they had crossed over. In the afternoon they were joined by members of the project team, to relate their discussion to the MASTER project.

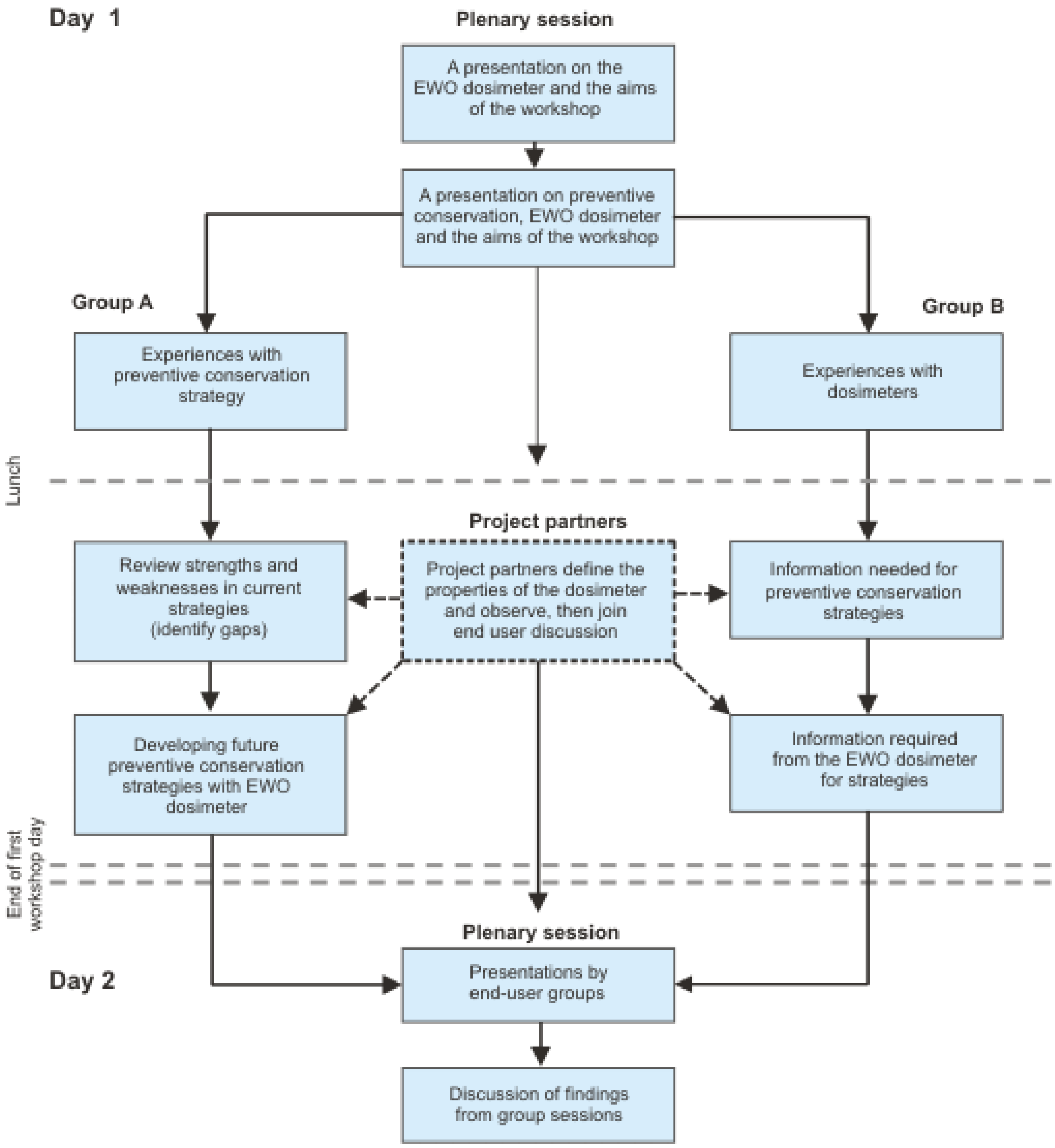

Figure 2.52: A schematic of the agenda of the first end-user workshop.

The end-user groups were asked to elect a chair and rapporteur amongst themselves, to guide and present their discussions. Half hour presentations were given by each group, responding to the prepared questions and stating what they would like to see in a dosimeter. These were responded to by the project team and kept for a facilitator's independent report and future reference by the project team.

Both groups arrived separately at the conclusion that they would like to see a visible change when the dosimeter responds to the environment. This was a very influential finding for the project, and was included in the final prototype. A point where the groups differed was the aspect of diagnosticity. One group were keen for all the parameters known to damage objects to be represented in a generic dosimeter. The other group was keen to have the parameters separated, so early diagnosis could be carried out by the institution. One dosimeter could not have both of these qualities but the suggestions were given consideration in different quarters of the project. The project developed the EWO-S dosimeter for monitoring SO_2, O_3 and NO_2, which contributes to the diagnosis of detected problems. This complements other readily available single parameter dosimeters that are readily available and frequently used in heritage institutions. Also, the strategy was developed to form a diagnostic process.

The end-user groups listed the desirable qualities of a new dosimeter, which included;

- Long- and short-term dosimeters
- Visual indication of change
- Individual risk factors detectable
- In-house analysis
- Clear instructions for use and interpretation
- Definitions of acceptable change
- Standards that fit into European framework
- Small
- Cheap
- Readily available
- Inert
- Non-toxic
- Durable
- Long shelf life
- Easy to handle

These recommendations were influential in the development of the dosimeters and the preventive conservation strategy. They were also useful criteria for the progress of the project, and were frequently referred to at project meetings.

The facilitator wrote a report of the workshop, documenting the outcomes. Again, it was felt to be desirable that this was carried out by someone not directly involved in the project. This served as valuable information for research priorities in the project.

2.2 Second End-user workshop

The second end-user workshop took place over two days in Trondheim, Norway, fifteen months after the previous workshop – at the halfway point of the project. Where possible, end-users from the previous workshops were invited (Table 2.6.2). With background knowledge of the project and the dosimeters, end-users would be more capable of critical appraisal of the project. This also provided continuity in the consultation process, and enabled a form of external monitoring for the project. Also, information from the first workshop could be used as a resource for the second.

The purpose of the workshop was to receive feedback on the project developments. As a result, the format was different from the first workshop and the end-users were not split into groups. Since the project was well underway, the format of the workshop was more didactic than discursive, giving presentations on project findings and showing developments and technical and scientific justifications. This gave end-users the opportunity to consider how the project was being carried out as well as what the project intended to achieve.

The facilitator introduced the second workshop. End-users were reminded of the recommendations they gave in the previous workshop by a presentation. This served as the criteria for reviewing the project developments. Presentations by the project team on the EWO-G and EWO-S dosimeters developments were given, pointing out the suggestions and recommendations that were met, as well as elements of the strategy. These were followed by question and answer sessions, led by the facilitator. At the time, two dosimeters had been developed: the EWO-G and EWO-S.

Table 2.6.2: A list of the end-users and facilitator present at the second end-user workshop in Trondheim.

Names of end-users (and professional affiliations at time of workshop)
Sarah Staniforth (National Trust, UK)
Jørgen Wadum (Chair of ICOM-CC and Royal Cabinet of Paintings Mauritshuis, Holland)
Astrid Brandt-Grau (Institut national du patrimoine, France)
Vasco Fassina (Soprintendenza al Patrimonio Storico Artistico e Demoetnoantroplogico del Veneto, Italy)
Márta Járó (Hungarian National Museum, Hungary)
David Thickett (English Heritage, UK)
Paula Menino Homem (Universidade do Porto, Portugal)
Marina van Bos (Royal Institute for Cultural Heritage, Belgium)
René Larsen (Danish Academy of Fine Arts, Denmark)
Facilitator: Laura Drysdale

The end-users were given the afternoon to digest and discuss the project team's presentations and then prepared a presentation for the next day in a separate room. They were presented with a one page document to aid discussion and remind them of their recommendations from the previous workshop. Only the facilitator and one member of the project team were present, to respond to technical questions and write down the key points of discussion. The project team waited in another room to respond to questions. Again, it was felt that any independent appraisal would be easier to achieve in the absence of the project team.

Issues such as; the relationship the dosimeter had with existing preventive conservation standards, costs of using the dosimeter (including analysis) and the potential for in-house analysis, its reliability, shelf life and exposure time and the possibility of combining the dosimeters were all discussed and reported.

The end-users presented thought provoking and encouraging feedback, and also offered recommendations and directions in which they would be interested in seeing the project take. This volunteered information was valuable since it was beyond what had been requested by the project team. This gave the project team further considerations when prioritising their work during the latter stages of the project.

Again, a facilitator’s report was written to discuss the outcomes of the project, which was used to further develop the project and prioritise research.

2.3 Final End-user workshop

The final workshop was open to all interested parties and was used to disseminate the project results to conservation professionals, heritage decisions-makers, scientists, researchers, curators and students. Held in January 2006, the format was two days of presentations, with regular opportunities for questions. It was attended by 80 people from over 20 different countries. The workshop was more oriented to disseminating information than the previous two, since the project was close to completion. However, the end-users were invited to attend to hear how their recommendations were taken on board. They also had the opportunity to give their independent opinions on the project.

The end-users provided an independent link between the project team and the workshop delegates, as people with knowledge of the project but not formally involved. After the technical presentations, the workshop involved a section where end-users had the opportunity to comment on the developments. This was facilitated and questions were prepared to start discussion but the topics and feedback were intentionally left open. Since the project team had no control over the feedback of the end-users, the workshop dissemination could demonstrate a level of authenticity that could not be achieved without independent appraisal.

3. The value of end-user workshops

The inclusion of end-user perspectives during the project was very useful and relevant, and has been the basis for some significant improvements to the project. These were insights from a group of experts that represented a wide range of institutions, experiences and countries, and allowed the project team to consider fresh perspectives that could be both insightful and challenging. The process does demand more resources from the project, and research directions are harder to predict at the outset of a project. However, the project has benefited from intensive, independent review through all stages, recommendations and indication on how to make the dosimeters as relevant to the conservation profession as possible and, in some cases, endorsement from experts in the field.

4 An end-user perspective on the consultation process

Comments written by the member of the end-user group: René Larsen, Danish Academy of Fine Arts.

The MASTER project aimed to provide conservator staff at museums, historic buildings and archives with a new global preventive conservation strategy for the protection of cultural property, based on an early warning strategy assessing the environmental impact of pollutants on organic objects. This included the development of the early warning dosimeters for organic materials (EWO).

The two dosimeters developed, EWO Generic dosimeter and EWO Specific dosimeter, are available at relative low costs, which is a prerequisite for their success at the relatively small and low resource cultural heritage protection market. Although the dosimeters are already of a quality and form that could easily be used in practise by end-users, ideas and activities for the development into more user friendly and easily readable equipment is continued by the partners.

The successful outcome of the MASTER project is due to a combination of qualified and professional project management and the open involvement of end-users' expertise in the development and evaluation of dosimeters. The success of this strategy is reflected in the resulting ready-for-use dosimeter prototypes of the dosimeters as well as the in the developed strategy for their use in practice. Applicability of the products into the end-user context and the end-user involvement should ease the entrance of these to the market.

The success of the project strategy was also the conclusion during and at the end of the end-user workshop. After two days of interesting presentations and discussions of the outcomes of the project, the panel of end-users representative reported that they felt that their recommendations during the project have been taken on board and that this should be an example to follow by other projects.

Other European projects have developed dosimeters such as that of the MIMIC project detecting the influence of light, climatic conditions and pollutants concentration. The IDAP parchment dosimeter is generic with specific relevance for collections of parchments and related materials meant for detection of the influence in general from the environment on the physical and chemical condition of the parchment.

In the workshop discussion it was pointed out that together with other tools, products like early warning dosimeters and dosimeters become more important in the growing demands and need for improved scientific quality in the cultural heritage conservation activities. However, the professional world of conservation is a low resource field with relatively few experts working around in small laboratories and workshops. This calls for implementation and marketing strategies that can ensure an effective and optimal use of resources and fast implementation of knowledge, results and products into the market. It was suggested that this may be achieved through international coordination and networking with respect to research, development, education and knowledge transference and product feed-back with the involvement of end-users in all the activity elements.

Moreover, it was suggested that a joint strategy for complementary and standardised use of early warning dosimeters and dosimeters as well as for exploitation of the valuable environmental and experimental data achieved and accumulated during the development of these systems should be established. The obvious basis for this would be a joint database designed also for input of new data and statistical analyses and mathematical modelling. Such databases are already available and could be further developed for this purpose, too.

2.7 Preventive Conservation Strategy

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1. Introduction

The Early Warning System has been developed for the long-term chemical deterioration of organic objects. The principle of the strategy is based on determining a level of chemical change in objects that can be considered acceptable within a certain period of time. The notion of acceptable change is relatively new to preventive conservation but crucial to making strategy appropriate to the needs of institutions. The system has been developed for archives, museums and historic houses. Each institution will have different needs but the Early Warning Strategy can be applied to all of them.

1.1 A strategic view of the dosimeter qualities

The synergistic quality of the EWO-G dosimeter fills a gap in preventive conservation. As effect dosimeters, both EWO dosimeters are closely linked to the interaction between object and environment, rather than the measurement of the environment to which an object or collection is exposed.

The strategy has also been developed to integrate the EWO dosimeters with existing conservation strategy and relate to environmental guidelines. This is beneficial to preventive conservation as a whole, and ensures the information from the EWO dosimeters is made as useful as possible. It is also a gap in preventive conservation, identified in literature reviews and expert workshops in this project.

Both dosimeters give a visible, easy-to-read response, which makes the process simple to apply. This reduces the amount of data and encourages prompt analysis, and better communication within the institution. Visible change, with more lit LEDs representing increased risk, also means that the dosimeters can be read in-house.

Using several EWO dosimeters, so locations can be compared, is also an option that can inform diagnostic monitoring. This can help determine how to solve a problem.

Also, if a problem was already known to exist, the EWO-Specific dosimeter could be used for diagnostic monitoring. Or if a risk assessment was being carried out, the EWO-Specific dosimeter could be used to determine the ‘Extent of damage’ factor, from which estimates of the amount of damage to be incurred in a given time frame is decided. The EWO-Generic dosimeter could be used to rate the different locations in one building for general aggressiveness. However, the routine monitoring described is the basis of an Early Warning System and will be described in much more detail.

1.2 The Early Warning System

The process of the preventive conservation strategy can be described by the diagram below (Figure 2.53). The stages develop from determining levels of change that can be considered acceptable, to the interpretation of the EWO-G dosimeter, its relationship to existing methods of preventive conservation and determining ways to mitigate risks. The levels of acceptable change are based on recommendations for different types of institution and existing research on object deterioration. They are expressed as points in section 2.8 and below.

2. Acceptable change

Collection policies, assessments of value and vulnerability involve the determination of a level of acceptable damage, or acceptable environmental conditions. What is considered acceptable will vary from institution to institution, depending on their resources and collections. The notion of 'acceptability' will vary between institutions, and how valued the collection is will play an important part in this.

Because of these variations, institutions will have different expectations of their environments. The EWO-G dosimeter response cannot be a strict dichotomy of 'acceptable environment' and 'unacceptable environment'. Results will be on a scale between these concepts. However, by breaking down the meaning of acceptability, it can be applied to different contexts. If a level of acceptable change of objects is decided upon, data would fall either side of this.

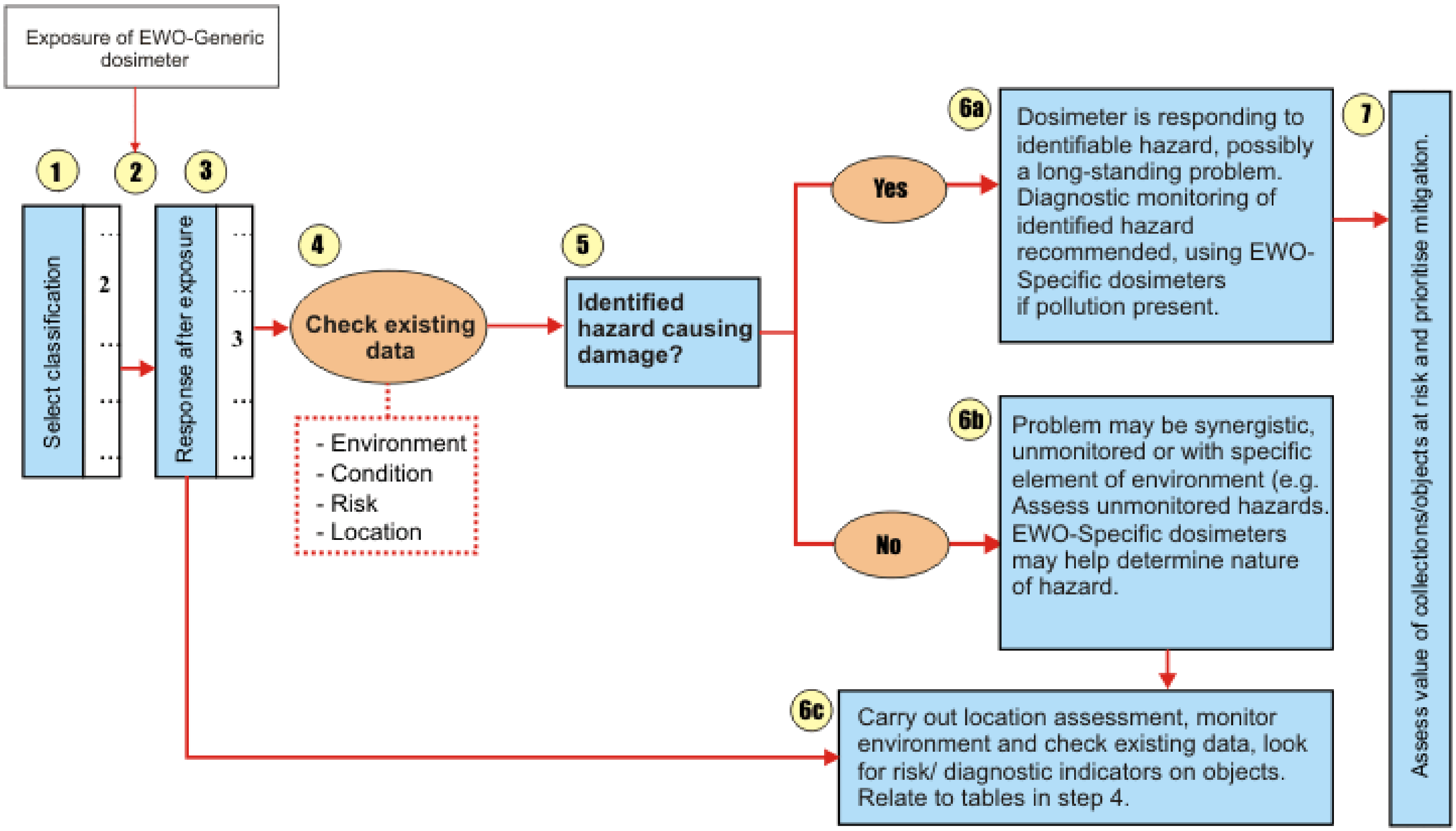


Figure 2.53: A schematic diagram of the early warning system. In some cases, all the stages may not be needed but all should be considered.

This strategy acknowledges that collections may have already been allocated space, based on existing institutional prioritisation. This gives the institution an opportunity to determine whether or not the valuable collections have the best environment. Assessments of value and environment may already exist, and the strategy integrates these factors. Classifications of building types can be linked to a class of control, which can also be on a five-point scale:

1. Archive store or storage vault
2. Purpose built museum gallery
3. Historic house, collection store
4. Open display in an open structure
5. Outside store with no control

The different kinds of collection housing, with their different aims, need not be directly compared, or measured on the same criteria. Each institution can be related to a broad band of environmental performance, which it could reasonably meet. This removes the possibility of inappropriate comparison, or institutions having unrealistic aims or performance indicators. Existing guidelines for different kinds of institutions show that this range of acceptable environments already exists. For example, Thomson (1986) classified museums to distinguish between purpose built galleries and historic buildings, and environmental standards have been developed specifically for archive buildings (BS5454:2000). The level of expected preservation from these guidelines corresponds directly to the order of institution types above.

Most preventive conservation methodologies involve classification of some kind, often in the form of rating scales. Examples of this include condition scoring (Keene, 1991), value assessment (van Huis, 1992; Cannon-Brookes, 1993), and environmental conditions such as lux hours (CIE, 1995) and dose levels (Larsen, 1996). The 1-5 classification of the EWO system is designed to compliment this (Table 2.7.1).

Table 2.7.1: The MASTER Trigger points for the EWO dosimeters.

Trigger point		**Isoperm values**	**UV values (mW/m2)**	**SO_2 (ppb)**	**NO_2 (ppb)**	**O_3 (ppb)**
1	Archive or storage vault	1.00 +	0-1	0.1	2	2.3
2	Purpose built museum	1.00-0.75	1-3.75	0.4	5	6
3	Historic house museum	0.75-0.60	3.75-15	2.5	10	13
4	Open display	0.60-0.44	15-37.5	4	20	25
5	Outside store	0.44 -0.00	37.5+	10	30	50

Institutions that obtain a response from the EWO-G dosimeter that is different from its expected environmental performance can then act upon the information. Choosing the expected environmental performance that the institution should meet will depend on the location and the prevalent microclimates. Table 2.7.2 illustrates how each level would relate to each building type, or level of performance.

For example, a historic house museum may aim for environmental control of 50% RH +/- 20%, 21°C +/-5°, 150,000 lux hours with 75 μW per lumen, 2.5 ppb SO_2, 10 ppb NO_2 and 13 ppb O_3. These environmental conditions are acceptable for a historic house but not for an archive store, and very difficult for some outside stores to meet. For the kind of institution, however, these values meet the expectations of environmental control. An archive store may aim for environmental control such as 40% RH +/- 5%, 16°C +/-1°, 5,000 lux hours with 10 μW per lumen, 0.1 ppb SO_2, 2 ppb NO_2 and 2.3 ppb O_3. This is not achievable for most kinds of collection housing but the performance expected from an archive store will be greater than many other stores. Acceptable levels of deterioration are implicit in the way collections are used.

3. 'Acceptable' risk from environment

Expectations of the range of environmental control are a useful starting point for assessing the suitability of display or storage environments. This is facilitated by grouping environmental conditions into several ranges. In many cases, the most valuable collections are likely to be better housed than less valuable collections: an accepted rate of deterioration. Collections may well be housed or used in a certain way already, based on an institution's collection policy (see 5.1), which could incorporate value, vulnerability, use and available resources. Thus the early warning system is based on existing resources, interests and priorities of the institution and is consequently realistic and relevant.

One may wish the level of deterioration to be a goal, rather than an expectation, which has the added advantage of transcending the existing situation in an institution's store or display. This bases acceptable environmental levels on the collection, rather than the building, and would be useful when considering the need to move a valuable collection to a better environment.

The table below (Table 2.7.2) relates the classification of the institution or location to the calibrated responses of the EWO-G dosimeter. The level of acceptability relates to the level of control decided upon by the institution. Therefore the levels 1-5 mean different things in different contexts. Some details of what constitutes a level of deterioration for each classification are provided below, and can be directly related to the trigger values in Table 2.7.1.

Table 2.7.2: Expectations of environmental control, based of type of building, and the meaning of different EWO levels for these expectations. (The response levels 1-5 are presented by light indicating bars on the display unit on the measurement instrument).

Kind of building	**Calibrated levels of EWO affected after exposure**				
	1	**2**	**3**	**4**	**5**
Archive store	Expected environment (acceptable)	Environment could be better	Environment is poor	Something is wrong with control	Serious problem with building or control
Purpose built museum gallery	Environment is very good	Expected environment (acceptable)	Environment could be better	Environment is poor	Something is wrong with control
Historic house museum	Excellent environment	Environment is very good	Expected environment (acceptable)	Environment could be better	Environment is poor
Open display in open structure	Dosimeter is not responding	Excellent environment	Environment is very good	Expected environment (acceptable)	Environment could be better
Outside store with no control	Dosimeter is not responding	Dosimeter isn't responding	Excellent environment	Environment is very good	Expected environment (acceptable)

3.1 Archive store

- Classification 1 will mostly be for archives where climate control has been achieved and air is purified. This is for optimum control that can be realistically achieved.
- The expectation is that there is tight control over environmental conditions in a purpose built archive, which is probably fitted with Heating, Ventilation, Air Conditioning (HVAC) with chemical filtration.
- If the dosimeter has been placed in a well-sealed showcase in a museum or a purpose built store, it may reach conditions similar to those of an archive.
- It is very probable that the location will be more of a storage space than an exhibition space, where environmental conditions are based on collection preservation rather than human comfort.
- This classification may be a target for collections that are very vulnerable or valuable, and not necessarily suitable for constant display.

3.2 Purpose built museum gallery

- Classification 2 will mostly be for purpose built exhibition spaces where climate control is possible, or the ambient environment is stable and free of pollutants - Thomson's Class 1 museum (Thomson, 1986).
- The levels of environmental conditions are high but achievable by purpose built museums and conform to accepted museum standards and ideas of good preservation for organic objects.

- If the dosimeter has been placed in a well-sealed showcase in a historic house, it may reach conditions similar to those of a purpose built museum.
- Similarly, an archive in a historic building may have an environment closer to a museum gallery.
- The space will probably meet the needs of human comfort and meet existing standards for museum exhibition spaces.
- The classification may be a target for small museums or museums in historic structures, particularly for valued or vulnerable collections.

3.3 Historic house museum

- Classification 3 will mostly be for museums in historic buildings and museums and galleries with limited resources but commitment to preservation - Thomson's Class 2 museum (Thomson, 1986).
- The levels of environmental conditions are levels that can be reasonable expected of a historic house museum but are still reasonably high. For example, Dutch archive limits for NO_2 (Havermans and Steemers, 2005) are higher than the MASTER trigger point.
- The rooms of a historic house may vary in terms of environmental control, with some rooms better than others. This classification should correspond to a typical gallery or room.
- Some museum stores, where resources are limited, may be in this classification.
- Most organic objects would be expected to be well preserved in this environment.

3.4 Open display in open structure

- Classification 4 responds to historic house collections on open display when the environment is difficult to control.
- Certain rooms in historic house museums may be classified as '4', where control is more difficult. An example is a historic house in an urban environment, where some rooms may have high pollution concentrations.
- The location may have open windows or galleries close to external walls.
- This may be a location in a museum where less valuable objects are displayed.
- Robust organic objects can be displayed here but not valuable or vulnerable objects. The values fall just outside those that might be recommended for a museum object.

3.5 Outside store with no control

- This classification is mostly for stores with very little control or protection. Environment is open to the outdoors in some respects and provides shelter rather than environmental control.
- This environment is not to be aspired to but may give an indication of how a location is performing in terms of collection preservation.
- There is little environmental control and there is significant influence from the external environment.

- Temperatures will vary among different European locations but this classification assumes a higher impact of temperature and relative humidity if left uncontrolled.
- It would be recommended that changes are made to the environment if the collection is in this classification.

3.6 Considerations for Environmental Classifications

Different parts of an institution may fall into different categories (for example objects in showcases and objects in galleries). Classification may involve other aspects or details about the collection or location. Below are some considerations for determining acceptable change for an institution. The ‘trigger points’ for different hazards can be used to make decisions on which classification is most appropriate to an institution.

- **Value of Collection** - Value assessment is a useful method of determining the level of acceptability and should be used at the early stages of an assessment. As well as being implicit in the use and accommodation of the collection, assessment of value may be useful for prioritising activities related to preventive conservation.

- **Use of collection** - Different types of institutions clearly have different uses for their collections but because that use may be institution wide, it might be taken for granted in a preventive conservation strategy. For example, an archive store, in which human comfort conditions are not important, may be colder than an historic house museum, and objects such as books and papers may be acidic, so chemical deterioration may be more important. In a historic house, where organic objects may be displayed in context with other materials, and visitors are present, relative humidity and temperature may be higher, and physical damage given higher priority. Uses of collections are often implicit within a conservation strategy but perhaps not mentioned unless there is more than one use.

- **Materials within the collection** - The materials in a collection are clearly an important part of preventive conservation strategy, since they will determine what hazards, and what levels of hazard, constitute a risk to the collection. Identification of vulnerable items, or materials sensitive to known agents of deterioration, is a common first step in strategy and practice. The MASTER trigger points are geared towards vulnerable materials, which may not be present in some collections. Although different kinds of materials are cited in the explanation for the levels chosen, individual collections may be more robust.

- **Collection condition** - A collection might be in poor condition and thought of as vulnerable, despite being made of material considered robust. The EWO dosimeters start from new but the collection itself may have a history that has rendered some objects vulnerable through past damage.

4. Components of preventive conservation strategy in Europe

Developing a preventive conservation strategy for the MASTER dosimeters requires consideration of several factors. A strategy must be: applicable, replicable, sensitive to the different types and contexts of collections, and flexible enough to be relevant to institutions with different resources. The literature search revealed a general shift from prescriptive standards to methodologies, and a lack of integration between existing methods (Taylor et al, 2003). Recently in preventive conservation, there has been a general shift from prescriptive standards to methodologies, and concern over the lack of integration between strategies. The dissemination of strategies within a European context has illustrated this (Putt & Häyhä, 2000).

Preventive conservation methods common to all countries and institution types are;

- Environmental assessment (including monitoring)
- Collection assessment (including condition surveys)
- Location assessment (including inspections of services)
- Risk assessment (including disaster planning)

These assessments, discussed in section 2.2, have advantages and disadvantages, as they assess collection preservation in different ways. Because these assessments attempt to do different things, hierarchies can be devised between them in terms of which should be carried out first. For a strategy based on early warning, the most useful criterion is speed of assessment. For example, a location assessment would produce knowledge quicker than an environmental monitoring programme, and can therefore direct further investigation.

The assessments are not exclusive of one another and results of one can be used to interpret another, to deepen understanding. For example, environmental data will have little meaning without an understanding of the building or location. In fact, they all record part of the same process of deterioration as part of a risk chain: presence of a hazard (release), the availability of the collection to the hazard (exposure), the interaction of hazard and collection (attack) and the effect of that interaction (consequence).

An overview of these preventive conservation assessments illustrates this (Figure 2.54). The axes relate to the point in time that the assessment refers to, past, present or future deterioration, and the kind of risk - catastrophes, like earthquakes, or gradual deterministic risks, like RH, or something between these extremes. The black circle represents actual object deterioration.

The diagram in Figure 2.54 illustrates the potential for overlap in these assessments, and where the overlaps exist. Also, deterioration between the past and the future may be related, especially for deterministic risks, so there is overlap between the assessments over time. Risk assessment largely involves assessment of damage that is yet to come, whereas condition assessment involves assessment of damage that has already happened. Their relationship with deterioration has different qualities. As a result, both assessments have large areas that fall outside what is actually happening to the objects *at that moment in time*. However, they might be the same risks documented in a different way. The space on the right hand side is for catastrophic risks, such as a fire, as they happen for which there is no assessment.

Many assessments cover potential changes from deterministic risks, whether through existing damage or measurement of exposure to a deterministic risk. The EWO dosimeters will also cover this area, being most closely related to environmental monitoring. The overlap between assessments suggests a strategic need to prioritise between them, but also that there is a logical meaning to their agreement or disagreement.

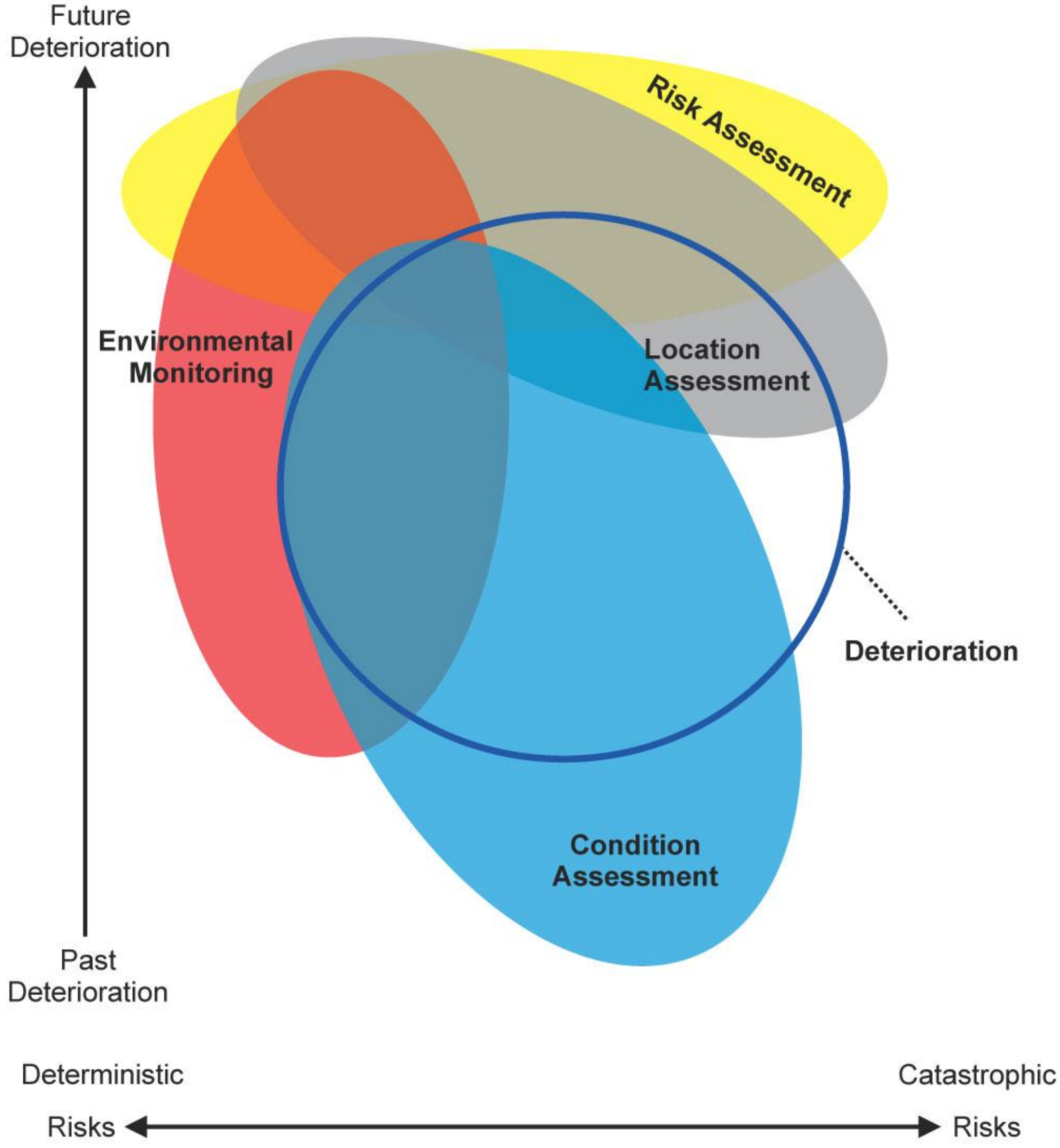


Figure 2.54: The relationship between preventive conservation assessments.

4.1 Methodologies in preventive conservation strategy

Often, these assessments will provide corroborating information. In the case where a store shows signs of damp, different methods of assessment will highlight this occurrence in different forms (mould on objects, high RH recorded, a problem identified in the location). However, because of the differences in these methods, information from the different assessments may appear to conflict. However, this, too, can be informative.

It is very likely that some of these data exist in institutions using the EWO dosimeters, so the possibility of comparing information does not require much additional effort. However, the early warning system makes no assumption of whether this is the case, or which assessments have been carried out, is not intended.

4.2 Building and location assessment

Since the building will be the biggest influence on environmental conditions, the environment will respond to problems caused by the building. Storage materials and internal factors that affect the environment, such as services and control methods, can also be included.

A quick assessment can lead to discovering visible problems without extensive data collection. “A material property may be observed and characterised by an observer on a broad quantitative scale; such characterizations may include terms [such] as ‘hot’, ‘cold’, ‘saturated’, or ‘dry’. In many situations these terms are adequate for descriptive communication or intuitive diagnostic analysis” (Henry, 2000). If the EWO-G results show an unacceptable environment, assessing the building and location is the quickest, cheapest and easiest assessment to carry out, and will identify or eliminate aggressive environmental factors. Consequently, location and environmental data will be complementary.

4.3 Risk assessment

The EWO dosimeters have similarities to risk assessment, as predictive tools. Assessing potential damage in locations means that preventive action can be taken. Risk assessment for museum collections takes account of four different factors, and multiplies them together to determine an overall risk score for each agent of deterioration to each collection in an institution (Waller, 1999; 2003). The factors considered are probability of hazards damaging the collection (P), the fraction of the collection susceptible to that risk (FS), the loss in value to the collection, were that risk to occur (LV) and the extent of impact (E). These are all expressed as scores between 0.00 and 1.00.

Each agent of deterioration, of the nine outlined by Michalski (1994), is considered for their potential to cause 1) rare, catastrophic, 2) severe, sporadic and 3) constant, mild risks (Waller, 1994). Since risk is projective, various kinds of data could be considered to assess risks, and there is potential for integration with other preventive conservation methods and museum operations (Michalski, 1994; Ashley-Smith, 1999). It will be a natural progression from short, general assessments, such as EWO dosimeters and location assessments, to risk assessment, since risk assessment is based on breaking down risks of deterioration into specific agents.

4.4 Environmental monitoring

Environmental monitoring clearly has much in common with the EWO dosimeters and is the clearest way to qualify and clarify EWO dosimeters' responses. Environmental monitoring involves inspection of single parameters, rather than overall 'aggressiveness', so the data help clarify which hazards are a problem to the collection, once the EWO-G dosimeter has determined that a problem exists. Since environmental monitoring involves single parameters, a general assessment that can be analysed is a useful precedent. It can also help investigate environmental effects that the EWO dosimeter does not measure, such as potential for physical deterioration or biological deterioration. The EWO-G dosimeter has the possible advantage of recording synergistic effects of risks, which will deepen understanding of environmental risk. Also, it provides a closer link to what is happening to the objects than environmental data alone. However, this will not necessarily always reflect the deterioration of the object. The condition of the collection still needs to be assessed if the most is to be made of 'negative' information, such as absence or accepted presence of a hazard.

4.5 Condition assessment

Condition assessment is complementary to other assessments, since there are various risks to collections that will not be detected by environmental data, or EWO dosimeters responses. Condition data provide useful indicators of deterioration from specific risks and also show evidence of deterioration outside the scope of the EWO dosimeters, such as pest infestations. Inherent deterioration is an important factor for many institutions, particularly archives. Equally, symptoms of object deterioration may not always be evident from observation, particularly long-term chemical deterioration, so the EWO dosimeters can offer insights that would not be seen in condition data for some time.

The EWO dosimeters represent the interaction between environment and objects. As a proxy for object condition, it has links with condition data as well as environmental data. Condition assessments look at effects, and the EWO-G response is an analogue of 'condition'. Condition data and EWO-G responses are both indicators of effect of the synergistic interaction between objects and their environment. Remove Bradley from references, too.

4.6 Common features

The EWO-G has something in common with all of these methods of assessment but also important differences. The EWO-G dosimeter is intended to enhance, rather than replace, established methods of preventive conservation. The EWO-G dosimeter should precede these assessments, providing broad, basic information quickly, which can be given more detail through further assessment. Once a problem has been identified by the interpretation of the EWO-G dosimeter, the stages of assessment can be carried out. An assessment of value also needs to be carried out to help prioritise actions that are to be taken. As mentioned before, such assessments may have already taken place.

5. Developing a preventive conservation strategy

By relating the MASTER system to several popular assessments, whilst maintaining independence from them, institutions will have control over the strategy, since the level of detail can be dictated by the situation rather than prescribed by the strategy. If more information is required, it can be directed. If no more information is required, resources are not wasted.

By carrying out basic, quick assessments first, then increasing detail and diagnosticity, the strategy takes into account the possibility that some institutions may have limited resources, and it maximises the efficiency of any data collection processes. This can be done by exploiting existing methods in preventive conservation. This also addresses the problem that too much unanalysed data is collected in preventive conservation. If the environment is considered unacceptable, and there are clear reasons why, it may be more suitable for the institution to deal with those evident problems than continue monitoring. If decisions require more information, or justification, the assessment can continue. Maximising the speed of the data collection process assists the communication of results, an identified gap in preventive conservation strategies.

5.1 Preventive conservation methods

No single assessment covers all of the issues in a preventive conservation strategy, nor do they approach issues in the same way. As a result, there is a possibility that different assessments will not reveal the same things. This uncertainty may lead to difficulty in collections management, as a result of collecting too much data, rather than collecting too little. The uncertainty inherent in each of these assessments may afford ambiguity when carried out in isolation but can be enlightening if other methods of assessment are involved and comparisons can be made (Figure 2.54).

These components of preventive conservation strategies all offer a perspective that can be enhanced by integration with the other assessments. The EWO-G has much in common with the area covered by environmental assessment but offers a more generic, synergistic approach. The tables below indicate that the EWO-G dosimeter would benefit from integration with each of the other assessments for different reasons. These will be better for some types of institution than others.

5.2 Uncertainty

The Early Warning System is primarily for organic objects and to assess chemical deterioration. Much like the assessments considered in Figure 2.54, there are occasions when the dosimeter converges with deterioration, and occasions when it does not. The potential uncertainties of the EWO-G dosimeter are data showing ‘aggression’ when the objects are not deteriorating (false-positives) and dosimeters showing acceptable levels of deterioration when the objects are deteriorating (false-negatives). As a result, the notion of testing for false-positives and false-negatives, using other forms of monitoring, will help reduce uncertainty in the strategy. Because of this, general monitoring of environment and condition should still be carried out, independently of the EWO-G dosimeter. To a certain extent they are potential uncertainties for all methods of assessment, so independent data may not determine if an EWO-G dosimeter is accurate or not but allow corroboration or discrepancies to be noted. False-positives are the response of a dosimeter to confounding factors that do not harm objects. False-negatives are the lack of response to hazards affecting the collection. The diagram below includes risks that the EWO-G dosimeter does not measure.

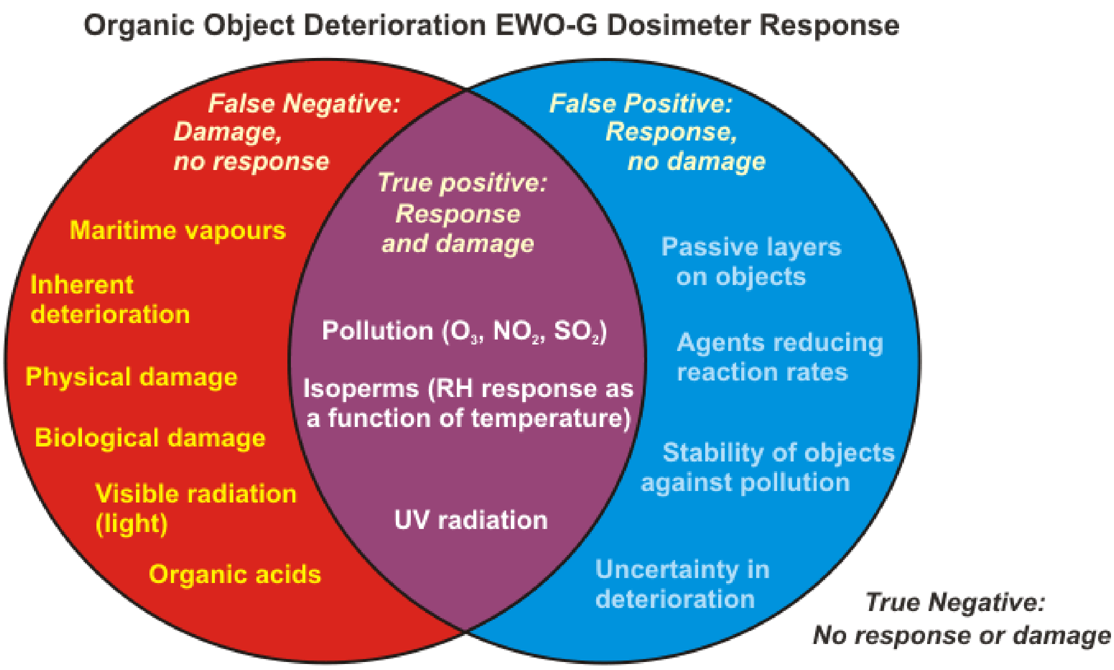


Figure 2.55: The overlap of the two circles represents deterioration that is picked up by the EWO-G dosimeter (true-positive). Anything outside the red, circle on the left is not deterioration. Anything outside the blue circle on the right is not picked up by the EWO-G dosimeter.

6. Relating EWO dosimeter response to existing preventive conservation methods

Methodologies should be independent of each other because different institutions will have different resources and ways of carrying out preventive conservation tasks. By maintaining independent assessment methods, assumptions about institutional practices and equipment are avoided. Once 'aggressive' environments have been identified, diagnostic monitoring can be based on the findings of the EWO-G dosimeter.

It is very unlikely that an institution will have no information about the environment before the EWO-G dosimeter was exposed. It is also impossible to predict what information will already be available to the institution, if any.

The different qualities of assessment methods often mean that they measure different things or measure in different ways (Taylor, 2005). For example, condition assessment may show fading from light that the EWO-G dosimeter does not reveal, or the EWO-G dosimeter may respond to pollution that environmental monitoring does not reveal. Whether or not they corroborate each other, there is information that can be gained from doing this. In fact, disagreement can sometimes be even more enlightening than agreement. The strategy is designed to utilise this data.

Below are two tables to compare the response of the EWO-G with data from other assessment methods. If several EWO-G dosimeters are exposed in different locations, there may be a number of agreements and disagreements to investigate. These tables below indicate that there are occasions where assessments disagree (Table 2.7.3) and when they agree (Table 2.7.4). The definition of 'problem' relates to the accepted level of risk for a collection.

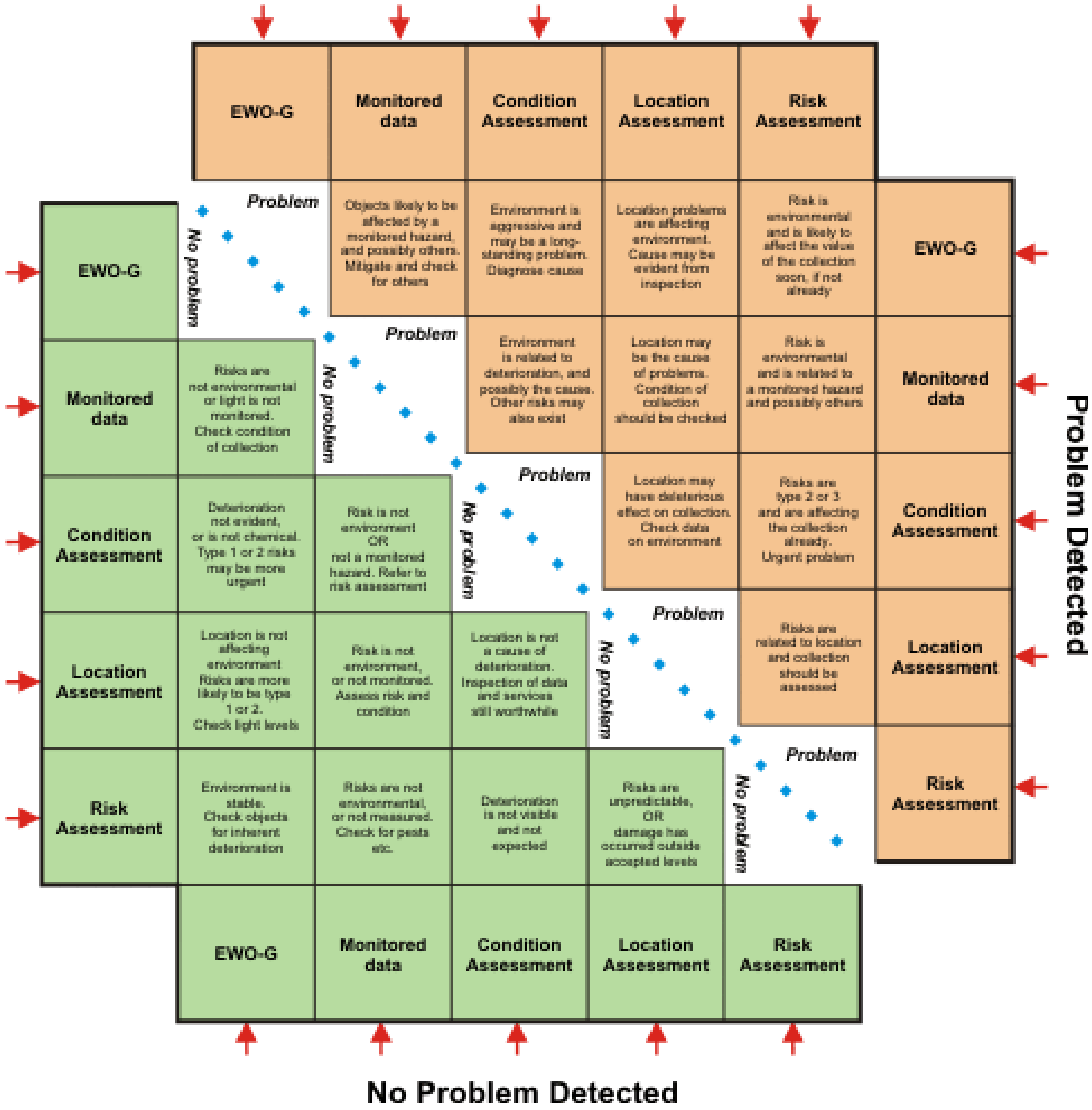
Table 2.7.3: Disagreement table. The possible reasons for conflicting assessments. Risk typology refers to Waller (1994).

	EWO-G	Monitored data	Condition Assessment	Location Assessment	Risk Assessment
EWO-G		Possible causes are light or very high RH. Relate to single parameters. Is deterioration chemical?	Inherent decay in object (look at RH), OR fading (look at light levels) OR damage is not chemical	Problem in location exists but is not (yet) affecting the environment OR is light or very high RH	Problem is light or very high RH, OR not yet affecting the collection, OR is a 'type 1' or 'type 2' risk
Monitored data	Response on EWO-G is synergistic, OR a hazard that is not monitored		Hazard not monitored, OR collection sensitive outside recommended levels	Problem in location exists but is not yet affecting the environment	Risk is not environmental OR not a monitored parameter
Condition Assessment	Early warning of future condition by chemical deterioration	Environment is not (yet) adversely affecting the collection		Location problem is not yet affecting the collection	Problem not (yet) affecting the collection, OR is a 'type 1' risk
Location Assessment	Problem is with control, not location, OR problem is very subtle	Problem is with control, not location, OR problem is very subtle	Problem is inherent in objects or environmental control		Risk not associated with location, such as handling
Risk Assessment	Risks are synergistic OR unmonitored 'type 3' risk OR present no loss of value	Materials not susceptible OR risk has been under-estimated	Objects more sensitive than recommended levels suggest	Location problem is not likely to increase	

Problem Detected

No Problem Detected

Table 2.7.4: Agreement table. The possible actions for corroborating assessments. Risk typology refers to Waller (1994).



The tables explain reasons for conflicting or corroborating results in different assessment. The reasons for agreement or disagreement between any two assessments can be found by connecting the rows and columns of those assessments.

6.1 Assessments that disagree

If the environmental data shows a problem detected, and the EWO-G dosimeter does not detect a problem, the two results can be looked up on the disagreement table. By drawing from the columns for positive and rows for negative, the reasons for conflicting data can be found. Of course, the cells where the row and column of the same assessment meet are blocked out.

6.2 Assessments that agree

If the results agree, there are two possible reasons – both assessments detect a problem or both assessments do not detect a problem. In these cases there may be actions that should be carried out as a result of this. Using the table 2.7.4? in the same way, cells can provide information on what to do next. The top right half (orange) is for when a problem is detected, the bottom left half (green) is for when no problem is detected.

Consulting the tables can help determine what the problem might be, and even diagnose problems or identify what to do next. If none of these data exist, and the EWO response is lower than expected, assessments should be carried out, possibly starting with the quickest assessment and continue with more detailed assessments until a problem is diagnosed.

Once the tables have been consulted, there may be clear steps to take. If the EWO response is higher than expected or desired, the problem may need to be identified (if comparison with other information has not revealed the answer). This may be a matter of environmental monitoring, including the EWO-Specific dosimeter for quantitative assessment of NO_2, O_3 and SO_2.

Diagnostic monitoring should be carried out at this stage, with intention to identify specific problems. Specific locations, including external locations should be monitored. However, there may be more than one problem.

6.3 Action to be taken

The presence of a problem, or an environment deemed ‘aggressive’, should be followed up by various direct checks of information, such as existing environmental data and assessments of the building and location. The relationship between the forms of assessment, and how these data can deepen each other’s understanding, must be established. There is little integration of these kinds in the literature.

An identified problem can only be confirmed by single parameter monitoring. There is a potential danger that if two or more hazards are present in high levels, and single parameter monitoring is carried out systematically, one will be detected first and mitigated whilst the other is not responded to. Conclusions about the environment may become ‘insufficiently generalised’ because certain hazards are detected early. In these cases, hazards may be dealt with one at a time. If new dosimeters are exposed once a hazard has been mitigated, further problems should be detected but at a later time.

If assessments indicate that there is, or will be, little deterioration, checking other data must still be carried out periodically. Since there is a scale of ‘acceptability’, information that does not suggest high risk can still be used to compare the suitability of different locations for organic objects. This can even be done with other dosimeters showing no immediate environmental threat to the collection, since there are degrees of acceptability. Some of the dosimeters may reach each point in a shorter space of time than others, which can indicate slight differences in ‘environmental aggressiveness’.

The overlap in assessments may help determine the kind of problem that the collection faces. Since no single assessment can identify all the problems a collection faces, consistency within different assessments can be informative. For example, positive information from both condition surveys and environmental monitoring would suggest that at least some of the deterioration found on collections is environmental damage. Consistent evidence of an acceptable environment may indicate no significant deterioration, or the best direction for further assessment of possible deterioration.

7. Diagnostic monitoring

There are two reasons to carry out diagnostic monitoring in this system. One is to identify and unknown hazard that has elicited a response from the EWO-G dosimeter that is lower than the accepted level. The other is to locate the cause or ingress of an identified hazard.

7.1 Unknown hazard

If an unknown hazard needs to be identified, this should be a process of eliminating parameters, based on existing information, particularly single parameter monitoring data. If no diagnostic information exists, assessments should be carried out to find the problem. This should involve carrying out the assessments previously mentioned until the problem is detected. Institutions may choose to set up a suite of single parameter monitoring devices to determine the type of hazard. The EWO-Specific dosimeter is designed to measure SO_2, O_3 and NO_2. The current lack of pollution monitoring is an identified gap in preventive conservation, and the EWO-S dosimeter makes this process much easier and accessible. The shorter exposure time of 1 month means that diagnostic monitoring can be carried out quickly, but without compromising on accuracy. The trigger points of the EWO-S dosimeter correspond to those of the pollution points of the EWO-G dosimeter.

7.2 Known hazard

Locating the cause of a problem may be more focused if the kind of hazard has been established. Depending on the information already available, gathering information about the location, object condition and environmental hazards is necessary. Diagnostic monitoring may be very short (one day) or may extend over four seasons. “The aim is to document apparent correlation between effect and postulated cause” (Henry 2000). From here, a hypothesis should be formed about the problem, and tested through the monitoring. Potential sources of the hazard should be identified in terms of ingress from outside (for example, high air exchange), services (HVAC malfunction or change in set-point) or internal generation (such as photocopiers producing Ozone). Again, the EWO-Specific dosimeter might be the most appropriate option to the conservator. Deployment of several dosimeters or sensors will help locate the problem.

8. Mitigation

The control of risk is often too varied to benefit from generalised techniques. Valuable case studies on control methods and solutions to specific problems exist, but choosing the most appropriate can be difficult. However, risks to collections are dependent on the outcome of a chain of events (Figure 2.56), and these can be generalised. Like any process or chain, there are strong and weak links that will determine success or failure. It is the identification of these critical points and pathways that leads to effective risk management.

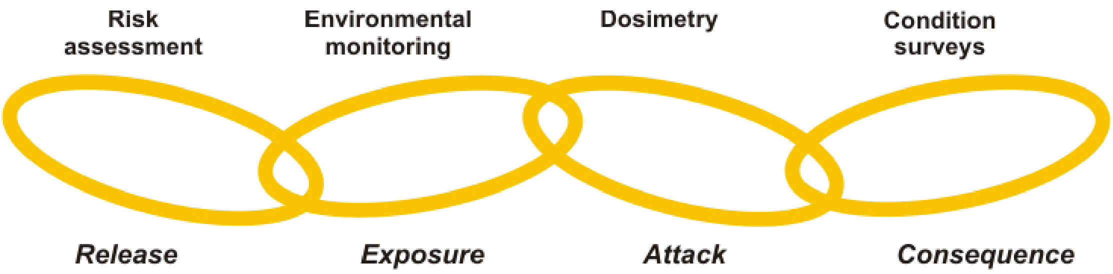


Figure 2.56: The risk chain: Various stages must be fulfilled before 'damage' occurs.

Dependency modelling involves specifying a 'top event', followed by identifying everything that leads up to that event. This can be based on the trigger point values developed for the EWO dosimeters, as the example (Figure 2.57) shows. The strength of a relationship is how dependent an outcome is on contributing factors, e.g. if all or some of the factors are required (Figure 2.57). Outcomes requiring all factors (AND dependencies) are points of weakness. Where alternative factors exist (OR dependencies), relationships are strong. Probabilities can be applied to each event, so deterministic risks can be modelled by defining damage over a period of time. This may have been carried out earlier, when determining positive and negative assessment results.

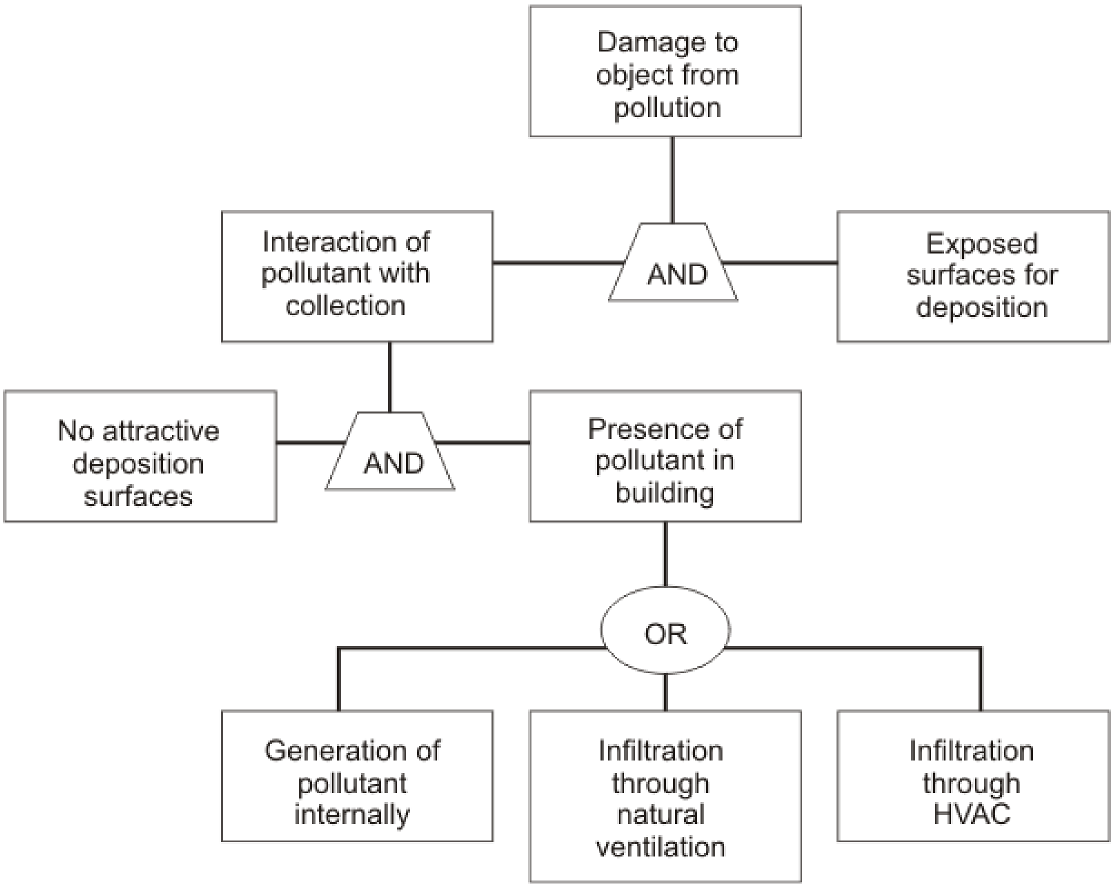


Figure 2.57: A diagram of a dependency model with a defined 'top event' and subordinate events and dependencies.

Dependency models can be applied to any process of which the user has a working knowledge, and fleshed out with specific information. It has a logical structure that can go into as much detail as required. Consequently, it has a wide range of applications within heritage preservation. By developing the processes involved for each risk, the specific factors relevant to an institution can be applied to the model. This can involve different kinds of information, including comparing EWO dosimeters deployed in different locations. Irrelevant aspects can be removed to develop a specific dependency model. This will make the decision on how to mitigate a problem easier, more justifiable and possibly more cost effective.

Figure 2.57 shows the two kinds of relationship in the context of pollution damage to organic collections. For the 'top event' to be successful, all of the lower events must be fulfilled. As the tree gets lower down, from exposed surfaces of objects to ingress from external sources, the relationships are more general. As a result, there are more alternatives that are available to completion of those events. These general issues can be further broken down, such as defining different possibilities for natural ventilation. The level of detail can be defined by the institution.

8.1 Deterministic risks

The nature of the dependency tree appears to be more suited to catastrophic risks, where events either happen or don’t, rather than gradual or cumulative risks. The environmental risks monitored by the EWO dosimeters are not certain, directly measurable events but the build up of damage over time. There is also the fact that the rate of these ‘events’ can be influenced indirectly. For example the deposition rate of pollution can be influenced by temperature and RH. Their presence alone will not result in the success or failure of an event but a decrease in temperature and RH will reduce the reaction rate. As a result, both the event itself, and relevant relationships do not have Yes-No functions to suggest that the chain is intact or broken.

However, the bands of preservation to determine acceptable and unacceptable environments can be used to define the point at which the event is successful (i.e. damage takes place). By providing a quantitative description of acceptability, the top event can be given a point at which it is considered to have been reached. This means that the deterministic qualities can be modelled.

Including probabilities in the model can increase its sophistication and representativeness. Since the outcome of all risks, catastrophic and deterministic, will depend on chance or situation, this can provide insight into the strength of a relationship. Determining the most cost effective way to break the risk chain, or decide which lower events should be attended to may depend on the probability of that event occurring. This can be achieved with scientific information, information related to the context and monitoring information.

8.2 Including monitoring data

The results of diagnostic monitoring can be directly related to the dependency model. This can help determine probabilities and provide information of which events can be eliminated to simplify the model. If the ‘top event’ is quantitatively defined, monitoring can also determine when the risk has reached a level or rate that is acceptable to the institution. In the example provided, the EWO-S dosimeter can provide the required information.

Different kinds of context-sensitive information can refine a dependency model and help the institution to concentrate on the events that are affording deterioration. Events that are unlikely or irrelevant can be eliminated, and the weak points in the risk chain more easily identified. For example, Figure 2.58 is a general model of damage from NO_2 as the top event.

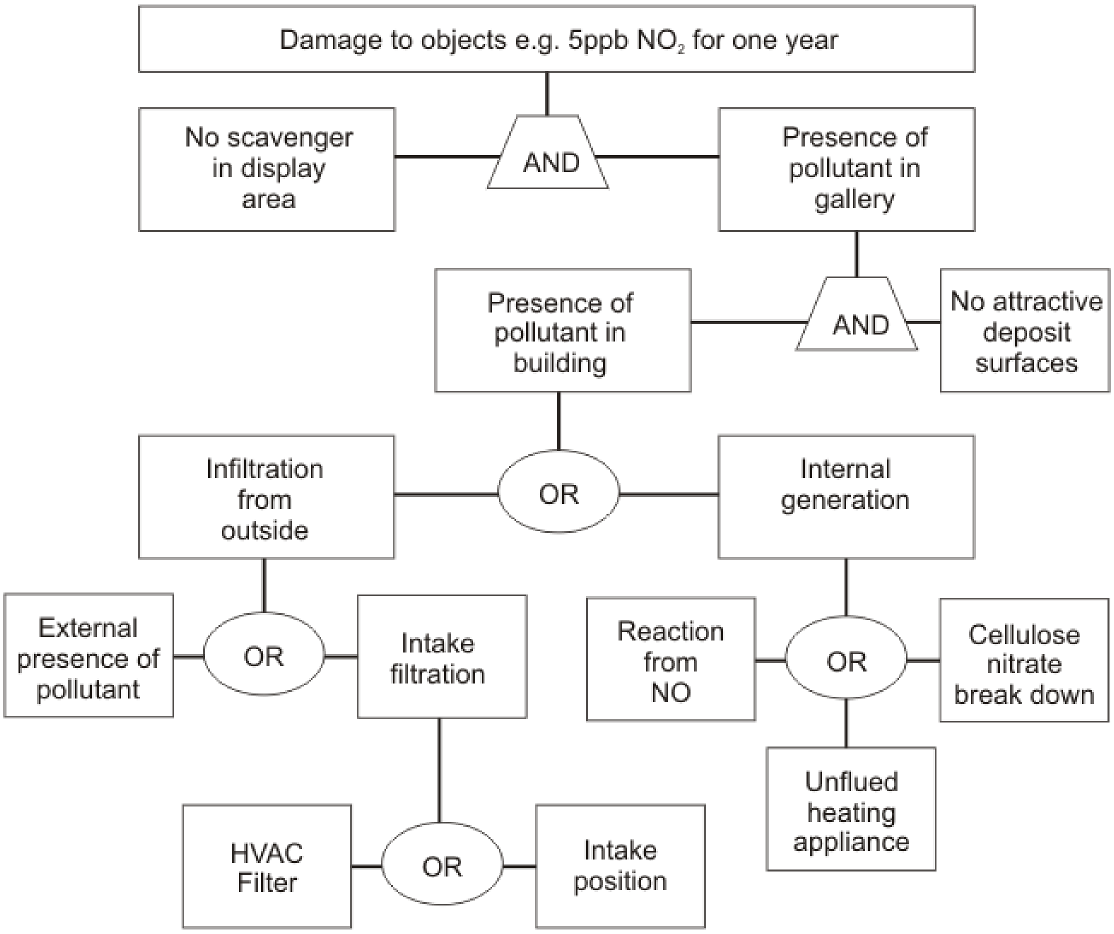


Figure 2.58: A generic dependency model with a 'top event' quantitatively defined by the levels develop for the MASTER project.

Currently, all of the lower level relationships are OR relationships (Figure 2.58), which are harder to break. Monitoring of a location can allow some of these events to be eliminated, so OR relationships become weaker AND relationships. As a result, there are clear points where mitigation can have a significant impact on the rate of NO_2 deterioration, reducing it to an acceptable level (Figure 2.59).

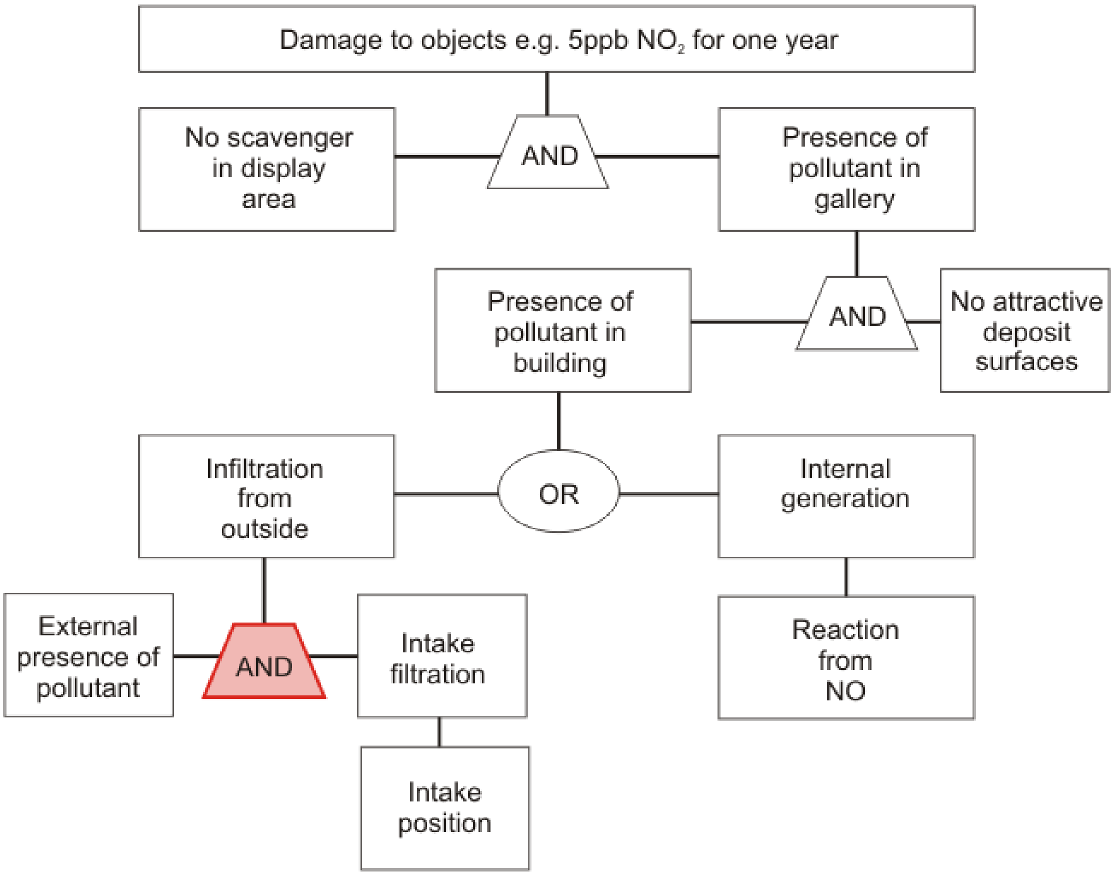


Figure 2.59: The dependency model after monitoring data has been reviewed. Alternatives can be eliminated to find critical pathways in the risk chain.

References see Chapter 6.9.

2.8 Assessing the museum environments with the EWO-G dosimeter

T. Grøntoft[1], J. Taylor[2], N. Blades[2], K. Hallett[3] and E. Dahlin[1]
[1)] NILU, [2)] UCL and [3)] HRP

The basis for an assessment of museum environments by using the EWO-G dosimeter is the calibration equation (Section 2.4).

Figure 2.60: The MASTER Field test set up on location in a museum, with exposure of the EWO dosimeters, gas sampling with passive samplers, exposure of organic materials and climate measurements. The calibration of the measured effects of the environmental parameters on the EWO-G dosimeter exposed on location, compared to that on organic museum objects was performed using literature values for observed effects of the parameters on organic museum objects.

The EWO dosimeter glass chip and its calibration is the same for the two versions with results measurements performed in the laboratory and on location respectively. Both versions are calibrated for a three months exposure period. The result-effect measured on the dosimeters after exposure in a museum is given as one number value. This value represents the change in UV absorption for the exposed dosimeter chip as compared to that measured for the unexposed dosimeter before exposure. For EWO-G dosimeter response to represent levels of acceptability of museum environments the dosimeter response is related to effects observed on real organic materials. This relationship is given from measures of effects on organic materials of single or combined environmental parameters, and related standards for acceptability.

Literature data for effects on objects observed for NO_2, O_3, UV-light and T were used (below). The temperature values were set for RH values of 45 %, 55 % and 65 % on the same isoperms. Five levels representing acceptable environments for museum locations with more and more relaxed control were determined. The EWO-G dosimeter response values, representing braking points between levels, were calculated from the calibration equation with single parameter values for the levels as input. Table 2.8.1 shows the input parameter values for the acceptability levels. A higher level means an expected higher deterioration rate of organic objects. This leads on to the derivation of the calibration points for the dosimeter, which were determined from comparison with degradation effects observed on organic objects exposed to similar doses of the environmental agents.

Table 2.8.1: Environmental parameter values used as input in the calibration equation to determine EWO-G dosimeter response for acceptability – location levels.

Calibration point – Acceptability location levels	**Trigger values**					
	NO_2 (ppb)	**O_3** (ppb)	**UV** (m W/m^2)	**T** (ºC) RH = 45 %	RH = 55 %	RH = 65 %
1 – Archive store	1	1.15	1	20.8	19.3	18.2
2 – Purpose built museum	2.5	3	3.75	22.9	21.4	20.2
3 – House museum	5	6.5	15	24.5	23	21.8
4 – Open structure	10	12.5	37.5	26.8	25.3	24.1
5 – External store with no control	15	25	37.5	29.0	27.6	26.2

Due to the additive nature of the calibration equation and the generally similar oxidative effects of NO_2 and O_3, the values for NO_2 and O_3 in Table 2.8.2 were set to half those given in the literature (Table 2.7.1 and below) for the effects of the single gases.

Table 2.8.2 gives the EWO-G dosimeter trigger responses, corresponding to the parameter values in Table 2.8.21.

Table 2.8.2: EWO-G dosimeter trigger responses values.

Calibration point - Acceptability location levels	**Trigger response (ads-units). Sign = 97.5 % (One sided)**		
	RH = 45 %	RH = 55 %	RH = 65 %
1 – Archive store	0.0114	0.0107	0.0103
2 – Purpose built museum gallery	0.0165	0.0159	0.0153
3 – Historic house museum	0.0258	0.0251	0.0246
4 – Open display in open structure	0.0418	0.0411	0.0405
5 – Outside store with no control	0.0612	0.0605	0.0598

From Table 2.8.2 the level of a result reading from the EWO-G dosimeter can be determined from the RH column most representative for the location of measurement. Comparison with the characteristics of the actual location then leads onwards to a preventive conservation evaluation.

Material effects, guidelines and location data used to determine the values for the different trigger levels in Table 2.7.1 and Table 2.8.1 are given below for the single parameters Nitrogen dioxide, Sulphur dioxide and Ozon:

Nitrogen Dioxide

1 – 2 ppb. Most sensitive organic colorants on silk or cotton change within 3 months, changes in typical plant dyes on cotton within five years. Detection limit for PPO dosimeter is 1.6 ppb. Paper loses strength after ten years. Paper changes colour after twenty years.
2 – 5 ppb. Typical organic plant dyes on silk and cotton change with one year. Natural organic colorants on paper change after five years.
3 – 10 ppb. Paper loses strength in two years, typical plant dyes on cotton and silk fade in six months
4 – 20 ppb. Paper loses physical strength after one year. Paper colour changes after two years.
5 – 30 ppb. Colour changes in wood after one year. Loss of physical strength in paper within six months. Typical natural organic colorants on paper change in one year.

Ozone

1 – 2.3 ppb. Detection limit for PPO. Most sensitive organic colorants change within six months. Paper and organic colorants on watercolour paper and silk change within twenty years
2 – 6 ppb. Photographic film dyes and images change within five years. Organic colorants on watercolour paper and silk and paper change within ten years.
3 – 13 ppb. Photographic film dyes and images change within two years. Incorporates US NBS for paper-based records. Paper and organic colorants on watercolour paper and silk change within five (almost exactly four) years.
4 – 25 ppb. Paper and organic colorants on watercolour paper and silk change in two years. Photographic film dyes and images change within one year.
5 – 50 ppb. Paper and organic colorants on watercolour paper and silk change in one year. Photographic film dyes and images change in six months.

Sulphur Dioxide

1 – 0.1 ppb. Good preservation for 100 years minimum.
2 – 0.4 ppb. Limit suggested by US National Bureau of Standards for paper-based records.
3 – Severe damage after 100 years.
4 – 4 ppb. Limit suggested by Gary Thomson in the *Museum Environment*.
5 – 10 ppb. Severe damage after 25 years.

Temperature and humidity

The calibration points suggested are based on the following existing standards from archives and museums and measured data. Below are the isoperm values that can be derived from established temperature and RH values and measured data.

Since the EWO-G dosimeter does not measure RH directly, but RH is routinely measured in heritage institutions, the calibration points can be related to different RH values that are likely to exist in museums – 45%, 55% and 65%. The constant isoperm values in Table 2.8.3 have been given a temperature range for each RH. The calibration is then more closely related to the isoperm value.

Table 2.8.3: Definition of dosimeter calibration points based on isoperm levels.

Calibration point	Isoperm values
1	1.00 and above
2	1.00-0.75
3	0.75-0.60
4	0.6-0.44
5	0.44 and below

Table 2.8.4: Isoperm values given from existing standards and real data.

Location	Average T & RH	Isoperm
Archives- BS5454: 2000 lowest values	16°C, 45 % RH	1.97
Archives- BS5454: 2000 highest	19°C, 55 % RH	1.05
Real data from archive store	20°C, 43% RH	1.05
Purpose built museum (Thomson, 1986)	21°C, 45% RH	0.85
Historic house museum (Thomson, 1986)	21°C, 55% RH	0.71
Summer in Madrid	27°C, 47% RH	0.41

Table 2.8.5: Definition of dosimeter calibration points: isoperm levels, temperature and RH.

Calibration point		Temperatures at different RHs		
Level	**Isoperm**	**45%**	**55%**	**65%**
1	**1.00 and above**	16.4-20.8°	15.0-19.3°	13.8-18.2°
2	**1.00-0.75**	20.8-22.9°	19.3-21.4°	18.2-20.2°
3	**0.75-0.60**	22.9-24.5°	21.4-23.0°	20.2-21.8°
4	**0.6-0.44**	24.5-26.8°	23.0-25.3°	21.8-24.1°
5	**0.44 and below**	26.8-29.0°	25.3-27.6°	24.1-26.2°

UV-light

Standards for UV in museums an archives are typically expressed as microwatts per lumen. The values provided are in MilliWatts per metre squared, rather than microwatts per lumen, since this means that the values are independent of lux level. Expressing microwatts without lux levels means the entire UV content cannot be determined. Since the EWO-G does not yet respond to visible radiation, the UV value must be independent. The convertions of existing standards in museums and archives are given below in Table 2.8.7.

Table 2.8.6: UV standards for conservation.

Source	Maximum UV level	Equals
Archives- BS5454:2000 lowest value	10 µW/lumen at 50 lux (lumen/m^2)	0,5 mW/m^2
Archives- BS5454:2000 highest values	10 µW/lumen at 200 lux	2 mW/m^2
Thomson[1]/English Heritage guidelines lowest values	75 µW/lumen at 50 lux	3.75 mW/m^2
Thomson[1]/ English Heritage guidelines highest values	75 µW/lumen at 200 lux	15 mW/m^2
British Museum Guidelines lowest values (light sensitive organic material)	75 µW/lumen at 50 lux	3.75 mW/m^2
British Museum Guidelines highest values (unpainted wood)	75 µW/lumen at 500 lux	37.5 mW/m^2
Heavily overcast sky UK example (external)	800 µW/lumen at 5000 lux	400 mW/m^2

1 (Thomson, 1986)

Table 2.8.7: Definition of dosimeter calibration points: UV.

Calibration point	UV values, mW/m2
1	0-1
2	1-3.75
3	3.75-15
4	15-37.5
5	37.5+

References see Chapter 6.10.

2.8.1 Case study from testing the EWO-G dosimeters in three different museums in Krakow, Poland

J. Czop[1], P. Karaszkiewicz[1] M. Obarzanowski[1] T. Grøntoft[2], J. Taylor[3]
[1] NMK, [2] NILU, [3] UCL

In addition to the Field test programme, the EWO-G dosimeters and the preventive conservation strategy were tested specifically by the National Museum of Krakow in order to make a real test of the MASTER Early warning concept as a whole. The results from both the Field test and the second “End-user test” is presented below.

Two sites of the National Museum of Krakow, Poland (MNK) participated in the project, which were both part of the initial ten field test sites, the Jan Matejko Museum (site 7) and the Karol Symanowski museum (site 8).

The Jan Matejko Museum is a typical 19th century tenement house with a historic house museum devoted to the most important Polish painter of the 19th century, Jan Matejko. The Museum is situated in his family house where he had his studio, home and where he stored his important art collection both painted by him, and work of other artists collected by Matejko. The museum displays paintings, real interiors with historic furniture, textiles and other materials typical for a house.

Figure 2.61: MASTER field test exposures indoors, inside and outside of a showcase, in the Jan Matejko House, Krakow, Poland.

The building is situated in the historic centre of Krakow (800 000 inhabitants), on the street with pedestrian traffic only (the nearest street with heavy car traffic runs about 200 m from it). The museum has no air conditioning and has a central heating system. As windows of the building are of the old, wooden construction, they are not sealed and outside air can penetrate them quite easily. Heaters are situated under the window openings.

As a measurement site, the room on the 2nd floor has been chosen. It contains no artefacts on open display – all pieces are protected in showcases made of metal and glass, lit with fluorescent light. This light is only switched on when visitors are present. The room has one window and no direct entrance from the staircase.

The gallery set of dosimeters was displayed on the wall opposite to window and the showcase dosimeters were displayed in the showcase situated in the same place.

The Karol Szymanowski Museum (ATMA) is situated in the small city Zakopane in the mountain region of Poland. It is devoted to one of the most important 20th c. Polish composers. Szymanowski spent several years in this house and in the 1970s the house was adopted for the museum. The building is typical of houses from this period in Zakopane: erected in the end of 19th c. and made entirely of wood. This is also a historic house. As in all wooden structures, the interior responds quickly to changes in the outdoor climate, but its influence is buffered by wooden walls. The heating system is based on the ceramic coal stoves, now fitted with electric heaters inserted into the stoves to replace the coal. The light sources are natural (side windows) and incandescent (spot lights). The interior has two display rooms with wooden furniture and some of Szymanowski's personal objects. There is only one small wooden showcase with glass door, not sealed. In this showcase, a small collection of personal belongings are exhibited.

Figure 2.62: The MASTER field test exposure outdoors of the Karol Szymanowski Museum, Zakopane, Poland.

The climate of the site is more severe than in Krakow due to high (up to 2500m) mountains in very close vicinity. Moreover the Museum is situated in the stream valley (the stream flows about 50 m from it) and two busy streets are just 50 m from the building.

In the ATMA site, both the gallery and showcase dosimeters were located in the room with a showcase. Its interior is partly protected from outside by a veranda and it has no direct connection with an entrance. The B dosimeters were situated in the corner opposite to the veranda entrance, where also the showcase dosimeter stands. Just 2 m from this site, the heating stove is located.

As a final test of performance of the EWO-G dosimeters, an additional measurement session was performed in the premises of MNK. One site was the Matejko House again, the other one was the Jozef Mehoffer House. This is also a historic house museum situated in the city centre, but at the street with heavy traffic. It has a different character of small city villa with a garden on the back. Thus, the Mehoffer House has features typical for a city dwelling (traffic, town climate) and rural one (small structure, garden close to it.). In fact, it has some common features of both Matejko and ATMA sites.

Figure 2.63: Exposure location (the red cross in picture) for the final test of the EWO-G dosimeter inside the Jozef Mehoffer House, Krakow, Poland.

The description of sites The Matejko House and ATMA, shows how different they are. Thus it was very interesting to compare them with MASTER dosimeters.

Preventive conservation strategy must be based on a systematic and repetitive approach. Otherwise it will not be possible to compare results and assess the dangers. The MASTER system is quite straightforward but on needs to take care, particularly when assessment tables are worked through. The steps leading to final solutions are the following:

Step 1. Selecting the site classification

In the case of MNK test sites both (and Mehoffer's) are Historic House Museums and belong to class 3 (Table 2.8.1, Table 2.8.2 and below). Such museums usually do not have any special protective installations, yet the majority of organic materials can be expected to be well preserved. The value, use, condition and materials of the contents did not provide any reason to modify this classification.

Step 2. Exposure of dosimeters

In the main part of the Master project, the EWO-G dosimeters were installed inside the showcases and outside of them. In the second verifying field test, where Matejko and Mehoffer Museums were evaluated, EWO-G dosimeters were installed in galleries outside showcases only. One must bear in mind that appropriate deployment of the dosimeter is vital for receiving proper data, so the place should be chosen with care.

Step 3. Relating the dosimeter response to the classification

Dosimeters were exposed for 4 * 3 months (in Mehoffer's 3 months). The laboratory measurements of the EWO-G reaction were performed. Following the class table the sites could be described as class 2 (Matejko) and class 1 (ATMA). Table 2.8.8 shows the data collected during measurements in site the Matejko House and ATMA.

Table 2.8.8: Measurement data from the Matejko House and the ATMA Museum.

Site	Location	NO_2 [ppb]	O_3 [ppb]	t [^oC]	UV [mW/m^2	EWO - G
Matejko	Gallery	7,4	0,2	21,2	0,09	0,0143
	Point	3	1			2
	Showcase	1,5	0,9	21,2	0,09	0,003
	Point	1	1			1
ATMA	Gallery	3,8	0,8	19,6	0	0,0177
	point	2	1			3
	Showcase	1,0	0,5	19,6	0	0,0053
	point	1	1			1

Step 4. Check existing data

From the tables below it is clearly seen that in both sites showcases have a good performance and properly protect objects exposed in them. The conflicting and corroborating assessments are given in tables below.

The **Matejko House**: *Results from exposure of EWO-G at the Gallery and Showcase.*

Determined expectation	***EWO-G dosimeter response level after exposure.*** *(The response level is presented by light indicating bars on the display unit on the measurement instrument).*				
	1	***2***	***3***	***4***	***5***
Archive	*Expected environment (acceptable)*	*Environment could be better*	*Environment is poor*	*Something is wrong with control*	*Serious problem with building or control*
Purpose built museum	*Environment is very good*	*Expected environment (acceptable)*	*Environment could be better*	*Environment is poor*	*Something is wrong with control*
Historic house museum	***Excellent environment***	***Environment is very good***	*Expected environment (acceptable)*	*Environment could be better*	*Environment is poor*
Open structure	*Dosimeter is not responding*	*Excellent environment*	*Environment is very good*	*Expected environment (acceptable)*	*Environment could be better*
External store with no control	*Dosimeter is not responding*	*Dosimeter is not responding*	*Excellent environment*	*Environment is very good*	*Expected environment (acceptable)*

The **ATMA Museum:** *Results from exposure of EWO-G at the Gallery and Showcase.*

Determined expectation	***EWO-G dosimeter response level after exposure.*** *(The response level is presented by light indicating bars on the display unit on the measurement instrument).*				
	1	***2***	***3***	***4***	***5***
Archive	*Expected environment (acceptable)*	*Environment could be better*	*Environment is poor*	*Something is wrong with control*	*Serious problem with building or control*
Purpose built museum	*Environment is very good*	*Expected environment (acceptable)*	*Environment could be better*	*Environment is poor*	*Something is wrong with control*
Historic house museum	***Excellent environment***	*Environment is very good*	***Expected environment (acceptable)***	*Environment could be better*	*Environment is poor*
Open structure	*Dosimeter is not responding*	*Excellent environment*	*Environment is very good*	*Expected environment (acceptable)*	*Environment could be better*
External store with no control	*Dosimeter is not responding*	*Dosimeter is not responding*	*Excellent environment*	*Environment is very good*	*Expected environment (acceptable)*

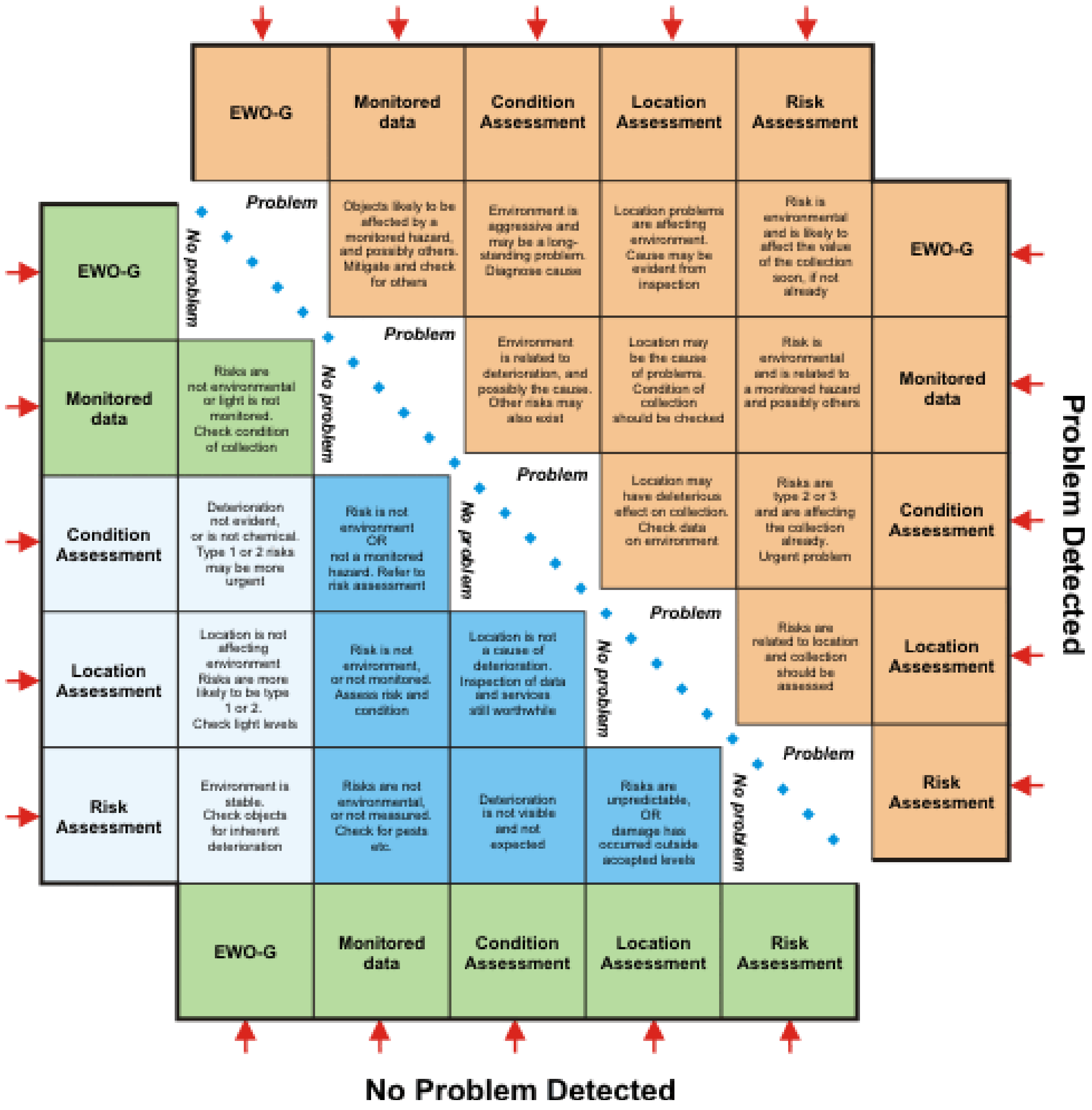
Table 2.8.9: Conflicting assessment of the showcase in the ATMA Museum, (based on comparison with the showcase in the Matejko House). Disagreements between methods are shaded in blue.

	EWO-G	Monitored data	Condition Assessment	Location Assessment	Risk Assessment
EWO-G		Possible causes are light or very high RH. Relate to single parameters. Is deterioration chemical?	Inherent decay in object (look at RH), OR fading (look at light levels) OR damage is not chemical	Problem in location exists but is not (yet) affecting the environment OR is light or very high RH	Problem is light or very high RH, OR not yet affecting the collection, OR is a 'type 1' or 'type 2' risk
Monitored data	Response on EWO-G is synergistic, OR a hazard that is not monitored		Hazard not monitored, OR collection sensitive outside recommended levels	Problem in location exists but is not yet affecting the environment	Risk is not environmental OR not a monitored parameter
Condition Assessment	Early warning of future condition by chemical deterioration	Environment is not (yet) adversely affecting the collection		Location problem is not yet affecting the collection	Problem not (yet) affecting the collection, OR is a 'type 1' risk
Location Assessment	Problem is with control, not location, OR problem is very subtle	Problem is with control, not location, OR problem is very subtle	Problem is inherent in objects or environmental control		Risk not associated with location, such as handling
Risk Assessment	Risks are synergistic OR unmonitored 'type 3' risk OR present no loss of value	Materials not susceptible OR risk has been under-estimated	Objects more sensitive than recommended levels suggest	Location problem is not likely to increase	

Problem Detected

No Problem Detected

Table 2.8.10: Corroborating assessments the showcase in the ATMA Museum, (based on comparison with the showcase in the Matejko House). Agreeements between methods are shaded in blue.



Step 5 – Identifying the problem

By referring to the agreement and disagreement tables, it appears that locations conditions for both sites are acceptable (ATMA Gallery), or better than acceptable. It is also clear, that a problem exists in the gallery at ATMA, which is an unmonitored chemical hazard or synergistic effect.

Step 6 – Diagnostic monitoring

It is probable that the higher response of EWO dosimeters in the ATMA gallery is caused by VOC from wooden walls of the room. It is also worth noting, that O_3 level is relatively high. Although the EWO-G response is less than the accepted level of deterioration, future priorities for preventive conservation can be determined.

Evaluating results

It is necessary to monitor the ATMA interior to find out the reason of the phenomena described above. As the reasons for them are not clear, it is not yet possible to suggest any remedies.

The additional measurements were carried out in two museums situated in Krakow: Jan Matejko Museum again and Jozef Mehoffer Museum. Both belong to the Historic House Museum type (classification 3). The measured data of EWO-G dosimeters exposed in in galleries, rather than showcases are given in the Table 2.8.11.

Table 2.8.11: Temperature, RH and light monitored at the Matejko and Mehoffer Museums.

Matejko vs Mehoffer EWO dosimeters					
	EWO	RH [%]	t [^oC]	UV [mW/m^2	Class Trigger point for 45% RH
MATEJKO	0.0138	34	20.5	1.8	Class 2 0.0165
MEHOFFER	0.0210	49	19.2	0.01	Class 3 0.0258

Recommendations

From environmental measurement, conditions in the Mehoffer Museum seem better than in the Matejko House: lower UV levels, a lower temperature and RH levels that also do not promote rapid chemical deterioration. On the other hand however, EWO-G levels are worse in Mehoffer’s. The reason for this is probably the higher level of air pollution from car traffic and RH. In Matejko’s House, besides too low RH which is not monitored by the EWO-G dosimeter, the threat may come from the higher levels of UV radiation.

On the base of the above-described experiments, it is possible to draw the following advice for the museum staff:

1. Before starting any research it is very important to learn as much as possible about the site to be analysed. All phenomena, which occur (such as fading of dyes, delaminating of paint layers), solid particles soiling etc should be recognised, recorded and discussed. At this stage the IMPACT calculator can be of help, for instance. Any information gathered by the personnel (cleaning personnel, guides, guards) are often of vital importance, as they can track down phenomena which can be omitted by someone visiting the site from time to time.

2. The sites location for deployment of the EWO dosimeters should be chosen on the basis of the factors mentioned above. In this case two approaches are possible: the monitoring site can be situated in the areas with most endangered risk, or close to the most important objects to be protected. The best solution could be to monitor both (often they are the same) but, when the cost and staff engagement is an issue, it seems that the sources are more important. Thus it is important to recognise the routes the pollutants can enter the site, as well as the inside sources. It is understandable of course, that routine microclimate (t, RH) measurements have to be carried out, too.

3. As the EWO-G dosimeters show the sum of possible deteriorating factors, the museum staff has to bear in mind that information provided is just an early warning that something is going wrong. Therefore, evaluation of possible deteriorating factors, such as air pollutants, light, heat, humidity have to be carried out when the dosimeters show the possible danger for the object. One should remember, however, that it is easy to gather a lot of varied data but it is difficult to draw a final conclusions from them. Thus the tables (matrices?) developed by MASTER should conclude the assessment of the hazards present.

4. The possible solutions for mitigation of deterioration are well known (but often not applied). Usually the first idea is to use a high-tech solution: air conditioning, filtering, new seals, RH stabilised showcases etc which are costly, difficult to maintain, and sometimes unreliable. With a sustainable approach, however, it is possible to improve the conditions by applying the simple solutions such as inserting air–traps at entrances (to lower the air exchange with outside), to separate objects which can deteriorate each other (e.g. oak objects and unstable glass), to lower the humidity stress by adding water vapour adsorbing (and desorbing) media, to screen southern windows, to lower temperature – the solutions are many.

5. There is no doubt that the preventive approach to conservation needs a deep understanding of deterioration phenomena. It also needs tools, which can show at best in advance, when and where the deterioration is unacceptable. The EWO dosimeters, when properly used, can and will play an important role in assessment of this danger. They are easy to use, the results are straightforward and, what is perhaps the most important feature of them, they force the museum people to think about the exhibition and storage of art objects in a holistic way.

2.8.2 User manual for the EWO dosimeters

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How to use the EWO-G dosimeter will be described below in the practical user manual that is made for the first prototype handheld measurement instrument. The working principle will be the same for coming versions although details in the construction etc. may differ. For the EWO-S dosimeter a short description of the working principle is given.

The EWO-G dosimeter

It is recommended that the EWO-G dosimeter is used together with the Preventive Conservation strategy developed by Centre for Sustainable Heritage, UCL as part of the MASTER project.

1. Important preparation before exposure of the dosimeter

Determine the location for the three months exposure of the EWO-G dosimeter:

Do

- *Chose an area where organic objects are located*
- *Ensure there is a good mixing of air, so hazards can be detected*
- *Ensure that any light/UV that will reach the objects also reaches the dosimeter*
- *Leave the dosimeter in its packaging until point of exposure*

Do not

- *Place the dosimeter by a heating source*
- *Place direct in sunlight*
- *Place near an open door or window*
- *Place near sources of dust and dirt*
- *Touch it or make it accessible for visitors to touch*

2. Preparation at the time of exposure

Do

- *Open the sealed Aluminium foil package with the EWO-G dosimeter chip*
- *Take out the dosimeter– Always hold the dosimeter in the grip.*
- *Before making the start measurement remove any back plater.*
- *Make the start value measurement of the EWO-G dosimeter in the accompanying portable measurement instrument.*
- *The start measurement is performed by putting the dosimeter chip into the slot at the side of the measurement instrument to the adjusted position and then by pressing the measurement button on the top panel. The identity of the chip (the internal identity number in the chip including the date and year of the start*

measurement) and the start value is stored in the memory circuit on the dosimeter chip.
- *Replace any back-plate.*
- *Mount the dosimeter on the chosen location for the three months of exposure of the dosimeter (*Figure 2.64*).*

Do not
- *Never touch the glass dosimeter with fingers or any other object. Always use the grip provided.*

Figure 2.64: The EWO-G dosimeter mounted at the location of exposure.

3. After Exposure

Measurements may be performed during the three months of exposure to get intermediate results.

Do
- *After the 3 months exposure, demount the dosimeter and take the measurement with the unit, the same way the start measurement was performed, to determine the response level for you exposure.*
- *Note the light indicating bars on the display unit corresponding to the numerically displayed value, and consult the acceptability – location, to evaluate your result (Table 2.8.12).*

Table 2.8.12: Acceptability – location table. Severity of registered response level for the EWO-G dosimeter in different locations. Levels 1 – 5 correspond to response intervals for the numerically measured effect on the EWO-G dosimeter.

Determined expectation	*EWO-G dosimeter response level after exposure. (The response level is presented by light indicating bars on the display unit on the measurement instrument).*				
	1	*2*	*3*	*4*	*5*
Archive	*Expected environment (acceptable)*	*Environment could be better*	*Environment is poor*	*Something is wrong with control*	*Serious problem with building or control*
Purpose built museum	*Environment is very good*	*Expected environment (acceptable)*	*Environment could be better*	*Environment is poor*	*Something is wrong with control*
Historic house museum	*Excellent environment*	*Environment is very good*	*Expected environment (acceptable)*	*Environment could be better*	*Environment is poor*
Open structure	*Dosimeter is not responding*	*Excellent environment*	*Environment is very good*	*Expected environment (acceptable)*	*Environment could be better*
External store with no control	*Dosimeter is not responding*	*Dosimeter is not responding*	*Excellent environment*	*Environment is very good*	*Expected environment (acceptable)*

The EWO-S dosimeter

The technical specifications for the EWO-S dosimeter are given in Chapter 2.2.6.2 and 2.2.6.3. The basic principle for the use of the EWO-S dosimeters is the same as those described in the user manual for the EWO-G dosimeter. Measurement of the dosimeter results is, however, made in separate different portable measurement instruments with different operation procedures for the two dosimeters. This makes the dosimeters applicable for their separate distinct purposes. The main differences between the EWO-G and the EWO-S dosimeters are:

1. For the EWO-S dosimeters an array of three dosimeter chips are placed in one holder instead of the one EWO-G dosimeter chip.

2. The EWO-S dosimeters are exposed under a specially designed shield where as the EWO-G dosimeter is exposed unshielded.

3. The exposure time for the EWO-S dosimeters is one month where as the EWO-G dosimeter should be exposed for three months.

4. The EWO-S dosimeters measures doses of single gases (NO_2, O_3 and SO_2) where as the EWO-G dosimeter measures a generic effect of a range of parameters (NO_2, O_3, T-RH, UV-light and SO_2. Therefore the interpretation of the results from the EWO-S dosimeter is a straightforward comparison with thresholds set for the pollutant gases in the location of measurement.

5. The EWO-S has the great advantage of being a passive gas sampler for which the measurement can be carried out on location with the portable instrument

3 Conclusion

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Technological relevance

The MASTER project has developed a new preventive conservation strategy for organic objects based on use of a new early warning system. The early warning system consists of dosimeters that can measure generic integrated effects of pollutants and climatic factors, and doses of specific gaseous pollutants, that have significant degradation effects on organic materials, in museums collections, historic buildings and archives. The dosimeters have been constructed to obtain results on location in the museums or archives, for the convenience of end users. The responsible conservation and administrative staff thus have full control of the process of evaluation of their environments, including dosimeter exposure, results reading and results interpretation based on preventive conservation and location knowledge. The criteria for evaluation of environmental conditions and preventive conservation at a location, based on the preventive conservation strategy developed by the project, will be included in the practical user manual that accompanies the EWO dosimeter system. Further preventive conservation guidelines, as described in Chapter 2.7, will be made available for end users. This includes a discussion of acceptable change and risk, of the components and development of preventive conservation strategy, including environmental, condition, location and risk assessment, and of preventive conservation methods, diagnosis and mitigation strategies based on EWO dosimetry. The aim of the preventive conservation strategy is to minimise negative effects of the environment and reduce costs of preventive conservation by applying suitable measures. By introducing this new preventive conservation strategy, the sustainable exploitation of cultural property can be enhanced.

Figure 3.1: User with EWO-G. Use of the EWO-G dosimeter in the MASTER field test.

Strategic relevance
Museum collections that include valuable organic objects are distributed around Europe and indeed the whole world. Many organic objects are very valuable as cultural and historical evidence and records. The large collections of written records in libraries and archives particularly come to mind. Other organic objects are particularly valuable because few are preserved from the past and because organic objects, such as e.g. clothing, tell a different story from the hard archaeological or more recent evidence. Some organic objects are among the most appreciated parts of the European cultural heritage, - e.g. the paintings collections in National Galleries and other exhibition spaces. European museum collections, including the organic objects, are considered important symbols of individual and collective achievement of European culture. The preservation of many highly important objects is a first priority.

The states of Europe invest large resources in their museums and in keeping their historical records for the future. The public interest in the European heritage displayed in museums is very high. This is demonstrated by the huge number of visitors to important exhibitions such as, e.g. the Viking ships in Norway, dress and costume museums around Europe or the very important National Galleries and other paintings collections.

Conservators in museums around Europe have to work with limited budget resources, and thus have to make large efforts to preserve museum objects they are responsible for, with the best and most sustainable methods available. The strategic impact of the MASTER dosimeter system and preventive conservation strategy is to ensure a sustainable protection and conservation of organic objects and to reduce the costs for preservation in the long term for these valuable objects of cultural heritage.

Figure 3.2: Organic objects of cultural heritage are vulnerable objects that have important stories to tell, as here for one of the last books with Maya script now kept in the British Library. Preventive conservation is very important for the objects.

Competitiveness

The competitiveness of European research in cultural heritage and its conservation clearly reflects the extraordinary meaning cultural heritage has for European regions and for their development, especially regarding the sustainable development of tourism, itself being one of the most dynamic industries. In several European countries, this is reflected in high investments in restoration of monuments and artworks.

The research in the MASTER project has contributed to European competitiveness by making the MASTER dosimeters available for the market and by help safeguarding important cultural assets of Europe.

The cultural assets of organic objects are important world wide as integrated elements in the material heritage of all societies. Organic objects originating in Europe are part of this global cultural heritage and at the same time distinguishes Europe as one special continent. Protection and restoration treatment can strongly increase the public interest in the art, as was seen e.g. after the restoration of the Sistine Chapel in Rome and the David statue in Florence. The actions of opening the conservation studios at the National Museums Liverpool to the public, and the two most recent ICOM-CC conferences in Brazil (public involvement in conservation) and The Hague (Our past – Your future) also show the increasing importance of protecting art.

Figure 3.3: Technological competitiveness in preventive conservation ensures European competitiveness in availability and communication of cultural assets.

Social and economic impact

The MASTER project will assist in the protection of the organic cultural heritage in museums, historical buildings, galleries for the future and help optimise the value of all the derived benefits in terms of economic, social and cultural utility. MASTER will assist in protecting for the future cultural assets that contribute to the European image of self and social identity.

Museum collections and historical buildings with organic objects attract tourists in large amounts and they are important for the total income from tourism. In addition the most well known objects are extensively used to promote both tourism and other activities that generate income and revenue. Libraries have an important function in education and information and for the cultural consciousness of people. The preservation of the old and more vulnerable documents in their collections, being original written sources, is most important. It has been estimated that in terms of economics for the whole of society public libraries roughly pay back their cost fourfold.

The MASTER project has provided technical methods and developed preventive conservation and remediation guidelines to meet stakeholder needs, in terms of the social and economic demands on them.

Innovation related activities
To be able to better protect the European and world wide cultural heritage of organic objects conservators and managers need to know more about which protection and conservation methods will improve preservation of the paintings given the environmental influences. They need to know more about the most important environmental factors that influence the state of preservation of the objects, and they need contributions to preventive conservation strategies that can help them obtain the best possible result for the preservation of their collections.

Systematic European research in the MASTER project has provided new Early Warning dosimeters for organic objects and a related preventive conservation strategy. This will make it possible for conservators and managers responsible for the cultural heritage of European organic objects to make better-informed decisions about best preventive conservation methods, and to acquire knowledge about how changes in the environment will influence the performance of the protective measures.

MASTER ha been a pioneering project in the field of the systematic study of the combined impact of pollutants and environmental hazards on organic objects in museums, galleries, historic buildings and archives.

MASTER has contributed to the development of the scientific basis for a sustainable preservation and conservation of the cultural heritage of organic objects.

MASTER has filled current gaps in knowledge and contributed to preventive conservation in terms of early warning technology for degrading environmental influences on organic objects and a preventive conservation strategy.

Figure 3.4: Conservation practice or research. The MASTER project has had an innovative technological and strategic approach to preventive conservation. - Research in the MASTER project at the Institute of Physical Chemistry, Freiburg Material Research Centre, Albert-Ludwigs University, Freiburg, Germany.

Policy

Particular attention has been given in the MASTER project to present the results to managers and policy makers. Policy makers and managers responsible for organic objects in collections were invited to the Final Workshop in London. This seminar also included people working with development of standards within the academic community and within the European Standardisation Organisation, CEN.

Figure 3.5: The MASTER project worked to communicate its results to policy makers and a main aim of the project was to influence preventive conservation policy in its practical and advisory roles.

In general terms the wider societal objective of the MASTER project has been to contribute to the safeguarding of the important European and world wide Cultural Heritage of organic objects in museums, historical building and archives. As a European project this effort would contribute to and strengthen the European experience of common identity across time and national borders. In this regard there is already a strong and clear context for the future direction of EU policy and research in the field of cultural heritage.

A number of specific references to cultural heritage in European Union policies, which are supported by the MASTER project, and which are important in underpinning research in the field of Protection of cultural heritage and associated conservation strategies, can be mentioned. Suffice it here to stress the aims of one of the most recent conventions on cultural heritage of Europe, which is supported by the MASTER project results, The Faro Convention:

The aims in the **Faro Convention (Framework Convention of the Council of Europe on the value of cultural heritage for society, 14 October 2005)** are stated: The parties to the convention:

a. recognise that rights relating to cultural heritage are inherent in the right to participate in cultural life, as defined in the Universal Declaration of Human Rights.

b. recognise individual and collective responsibility towards cultural heritage.
c. emphasise that the conservation of cultural heritage and its sustainability use have human development and quality of life as their goal.
d. take necessary steps to apply the provisions of this convention concerning:
   - the role of cultural heritage in the construction of a peaceful and democratic society, and in the process of sustainable development and the promotion of cultural diversity.
   - greater synergy of competencies among all public, institutional and private actors concerned.

Figure 3.6: Preventive conservation efforts such as the work in the MASTER project aim to safeguard the rights of the citizens in relation to cultural heritage, as stated in the Faro Convention. – Osborne House, Isle of Wight, England (Image courtesy of English Heritage).

4 Dissemination and exploitation of results

The MASTER project has created two early warning dosimeters and a preventive conservation strategy to be used integrated into preventive conservation activities in heritage institutions. As a result, it is vital for the project's output to be relevant for that field and for the integration to be smooth and sustained.

The dissemination of the MASTER project has opened dialogue with a wide range of end-users and European cultural heritage institutions on the issues of preventive conservation strategies.

A brochure was designed and distributed by all partners to a wide range of heritage professionals. The distribution of brochures was monitored and consistently carried out for the duration of the project. These were mailed to heritage institutions, distributed at conferences and symposiums, displayed at test sites and used to supplement talks. It was intended that dissemination should be diverse in terms of audience and method, to ensure that messages were communicated. The project team also developed a website that disseminated information about the project as it progressed.

Figure 4.1: Results from the MASTER project were presented at the Wignacourt Collegiate Museum, Rabat, Malta during the COST Action G8 Training School.

Results from the MASTER project were presented at the COST Action G8 Training School in Malta in November 2004 (Figure 4.1). During this event delegates from Europe and overseas discussed about the project and development of the dosimeters for use in heritage institutions. Wider issues of training in preventive conservation were also raised and the possibility of disseminating the project results in this way.

The emphasis of the dissemination on communicating with project results with a wide range of stakeholders, peers and end-users has helped develop a socio-economic dimension to the project and outlined the benefits to museums, historic buildings, archives and other institutions and the best way that they can optimise those benefits. The commitment of the project to consultation at all stages of the project meant that the Final Workshop arranged in London in January 2006, benefited from well developed viewpoints of conservation scientists and end-users that were independent of the project. It also meant that dissemination had not only reached a broad range of heritage professionals but the dissemination was detailed and in-depth. This allowed the end-user group, that included decision-makers and teachers to further communicate the aims and results of the project.

The final workshop disseminated the project information to a wide range of people in the conservation field throughout Europe. This has also led to delegates requesting the project results to be presented at forthcoming conferences and workshops. The response at and after the workshop was very positive and has led to ideas of how the project results can be used by heritage institutions, such as sending out MASTER dosimeters to delegates' institutions that can be analysed by the MASTER project team and inclusion in training programmes.

The diverse and consistent dissemination of the MASTER project results has allowed interest in the MASTER project and the EWO dosimeters to be generated internationally, particularly in Europe but also in USA, Canada and Australia. Further ways of dissemination have been devised including a publication strategy, which will allow the project results to be accessed by a wide number of heritage professionals.

The MASTER EWO technology will be further developed with the help of SME's, in the sectors of production, marketing and sale. Marketing will be performed in close co-operation with end users and their experience with the product and further evaluation of its usefulness will be essential. The involvement of end-users from museums and galleries gives potential for a wide impact. Besides the social and economic benefits on the level of the society there is also potential for SME profit from production and marketing.

5 Main literature produced

Peer Reviewed Articles:

Authors	Date	Title	Journal	Reference
Blades N, Dahlin E, Henriksen J, Grøntoft T, Rentmeister S, Cassar M, Taylor J, Lazaridis, M and Howell D	2004	The MASTER project: An Early Warning Sensor for Environmental Deterioration of Paper and other Organic Materials’	*Durability and paper writing: proceedings of the international conference*. Ed.s J Kolar, M Strlic and J Havermans, Ljubljana: National and University Library, Slovenia, pp. 14-15	
Marcin Alexy, Gundula Voss, Jürgen Heinze	June, 2005	Optochemical sensor for determining ozone based on novel soluble indigo dyes immobilised in a highly permeable polymeric film	Anal. Bioanal. Chem., 382, 2005, p. 1628–1641	
Elin Dahlin, Terje Grøntoft, Sara Rentmeister, Christopher Calnan, Janusz Czop, David Howell, Christoph Pitzen and Anne Sommer Larsen	Sept. 2005	Development of an early warning sensor for assessing deterioration of organic materials indoor in museums, historic buildings and archives	*ICOM-CC Committee for Conservation 14th Triennial Meeting, The Hague.* Ed. by: I. Verger. London, James and James. pp. 617-624.	
Joel Taylor, Nigel Blades and May Cassar	2006	Dependency Modelling for Cultural Heritage	Proceedings of the 7th EC conference *Safeguarded Cultural Heritage - Understanding & Viability for the Enlarged Europe*. Prague May 31st - June 3rd, 2006 (forthcoming)	
Terje Grøntoft, Elin Dahlin, Sara Rentmeister, Michael Hanko, Jürgen Heinze, Joel Taylor, Nigel Blades and May Cassar	2006	“An Early Warning System for Organic materials in Museums, Historic Buildings and Archives”	Proceedings of the 7th EC conference *Safeguarded Cultural Heritage - Understanding & Viability for the Enlarged Europe*. Prague May 31st - June 3rd, 2006 (forthcoming)	

Non-refereed literature:

Authors/Editors	Date	Title	Event	Refe-rence	Type[1]
Marcin Alexy, Michael Hanko, Sara Rentmeister and Jürgen Heinze	Feb. 2003	http://www.pce.uni-freiburg.de/bereiche/sensorik_e.html			Web-site
Elin Dahlin, May Cassar, Jürgen Heinze, Mihalis Lazaridis, Januz Czop, David Howell and Anne Sommer Larsen	April 2003	The MASTER project a new Early Warning System for Protection of Organic objects in Museums and Histroic Buildings	Indoor Air Quality 2003, Univeristy of East Anglia, UK, April 2003	http:www.isac.cnr.it/iaq2004	Poster
Marcin Alexy, Michael Hanko, Sara Rentmeister andJürgen Heinze	May 2003	Schnelle Analytik und Langzeit-monitoring von Schadgasen auf der Basis von Farbstoff-reaktionen in Polymerfilmen	102. Bunsentagung, Kiel, Germany		Oral presen-tation
Michael Hanko, Marcin Alexy, Sara Rentmeister and Jürgen Heinze	Oct. 2003	Entwicklung von optochemischen Sensoren zur Analyse von Luftschadstoffen	12. FMF-Kolloquium		Oral presen-tation
Anne Sommer Larsen	November 2003	The concept of the MASTER project	Meeting at the Nordic Conservation Association, Oslo, Norway		Oral presen-tation
Elin Dahlin	April 2004	“Preventive Conservation strategies for Protection of Organic Objects in Museums, Historic Buildings and Archives”.	EC "Clustering Workshop", "Protecting Europe's Cultural Heritage through EU Technological Research", European Commission, Brussels		Abstract and Oral presen-tation
Marcin Alexy, Michael Hanko, Sara Rentmeister and Jürgen Heinze	April 2004	Optochemische Schadgassensoren für die Umwelt-, Arbeitsplatz- und Innenraumanalytik	FMF-Journal 2003		
Sara Rentmeister	September 2004	‘Novel selective opto-chemical sensor chips for the	6th European Commission Conference on Sustaining		Abstract and oral presen-

[1] Type: Abstract, Newsletter, Oral Presentation, Paper, Poster, Proceedings, Report, Thesis.

		measurements of ozone, nitrogen and sulphur dioxide', UK	Europe's Cultural Heritage: from Research to Policy, London, UK 1-3 September 2004.		tation
Januz Chop, Michal Obarazanowski	October 2004	Presentation of the MASTER project	Celebration of the National Museum in Krakow 125 years anniversary		Printed pamphlet (in Polish) and oral presen-tation
Elin Dahlin and Terje Grøntoft	November 2004	"Preventive Conservation strategies for Protection of Organic Objects in Museums, Historic Buildings and Archives".	COST Action G8 Training School, Malta Centre for Restoration, Valetta, Malta		Oral presen-tation and a CD which has been distru-buted through COST.
E. Dahlin, et. al.	November 2004	The MASTER-project, a new Early Warning System for Protection of Organic objects in Museums and Historic Buildings	6th Indoor Air Quality 2004', CNR Padua, Italy	http://www.iaq.dk/iap.htm	Abstract and oral presen-tation
May Cassar	January 2005	"Preventive conservation: Results from a Survey of Current European Practice"	Louvre, Paris, France		Oral presen-tation
Sara Rentmeister, Marcin Alexy, Michael Hanko and Jürgen Heinze	April 2005	Preventive Conservation Strategies for Protection of Organic Objects in Museums, Historic Buildings and Archives	FMF-Journal 2004		Report
Anna Kohout	April 2005	Feine Sensoren für Kunst	Newspaper article (Badische-Zeitung)		Newspaper article
Joel Taylor	April 2005	'The MASTER project: Preventive conservation strategies for protection of organic objects in museums, historic buildings and archives'	Canberra, National Archives (open to all members of AICCM ACT)		Oral presen-tation

Joel Taylor	April 2005	'The MASTER project: Preventive conservation strategies for protection of organic objects in museums, historic buildings and archives'	Sydney National Maritime Museum (open to all members of AICCM New South Wales)		Oral presen-tation
Joel Taylor	April 2005	'The MASTER project: Preventive conservation strategies for protection of organic objects in museums, historic buildings and archives'	Brisbane Queensland Art Gallery (open to all members of AICCM Queensland)		Oral presen-tation
Christoph Waller	July 2005		University of Stuttgart, Germany		Lecture about pollution inside museums
Sara Rentmeister, Michael Hanko and Jürgen Heinze	July/Aug. 2005	Novel early warning sensors for museums, historic buildings and archives by determination of the gaseous pollutants nitrogen dioxide, ozone and sulphur dioxide	Museum aktuell, 117, 2005, p. 23-26 ISSN 1433-3848		
Michael Hanko, Marcin Alexy, Sara Rentmeister and Jürgen Heinze	Oct. 2005	Neue optochemische Sensoren für den Nachweis toxischer Gase	14. FMF-Kolloquium		Oral presen-tation
Janusz Czop	November 2005	Preventive conservation-the role museum in research projects. Presentation of the MASTER project	ICOM- Polish Committee meeting Warsaw, Poland		Confe-rence abstract+ oral presen-tation
Elin Dahlin	January 2006	Introduction to the The MASTER-project	Final workshop for the MASTER project. UCL, London	http://www.nilu/master.no	Abstract and Oral presen-tation
Sara Rentmeister, Michael Hanko and Jürgen Heinze	January 2006	Specific Dosimeters for the Museum Environment	MASTER Project Final Workshop, London, UK	http://www.nilu/master.no	Confe-rence abstract+ oral presen-tation

Terje Grøntoft	January 2006	The EWO-generic Dosimeters	MASTER Project Final Workshop, London, UK	http:// www.nilu/ master.no	Abstract and Oral presen-tation
Terje Grøntoft	January 2006	The MASTER field test	MASTER Project Final Workshop, London, UK	http:// www.nilu/ master.no	Abstract and Oral presen-tation
Kathryn Hallett	January 2006	Relationship between dosimeters and organic objects	MASTER Project Final Workshop, London, UK	http:// www.nilu/ master.no	Abstract and Oral presen-tation
Nigel Blades	January 2006	Standards, monitoring and dosimetry	MASTER Project Final Workshop, London, UK	http:// www.nilu/ master.no	Abstract and Oral presen-tation
Joel Taylor	January 2006	The Preventive Conservation strategy	MASTER Project Final Workshop, London, UK	http:// www.nilu/ master.no	Abstract and Oral presen-tation
Janusz Czop and Michal Obarazanowski	January 2006	An end user application of the MASTER dosimeters	MASTER Project Final Workshop, London, UK	http:// www.nilu/ master.no	Abstract and Oral presen-tation

6 List of References

6.1 References from Ch. 1

Dahlin, E., Grøntoft, T., Henriksen, J.F., Rentmeister, S., Hanko, M., Heinze, J., Taylor, J., Blades, N., Marshall, S. and Hallett, K. (2005) Report on assessment of deterioration of EWO dosimeters and silk and paper samples after exposure in 10 different European Museums. D. 3.2. Restricted report to the European Commission.

Grøntoft, T., Henriksen J. F., Dahlin, E., Lazaridis, M., Czop, J., Sommer-Larsen, A., Hallett, K., Calnan, C., Pitzen, C. and Cassar, J.A. (2005) Sensor and environmental data from the field test programme. Deliverable no. D. 3.1, WP 3. Restricted datafile report to the European Commission.

Grøntoft, T., Dahlin, E., Henriksen J. F., Danielsen, T., Rentmeister S., Hanko M., Heinze J., Taylor J., Blades N. and Hallett, K. (2006) Final prototype of EWO-dosimeter as part of the early warning system. D. 2. WP2. Restricted report to the European Commission.

Keene, S. (1991) Audits of care: a framework for collections condition surveys. In: *Storage*. Ed. by: M. Norman and V. Todd. UKIC. pp. 6-16.

Michalski, S. (1994) A systematic approach to preservation: description and integration with other museum activities. In: *Preventive conservation: practice, theory and research*. Ed. by: A. Roy and P. Smith. London, IIC. pp. 8-11.

Mills, J.S. and White, R. (1994) The organic chemistry of museum objects. 2nd Edition. Oxford, Butterworth-Heinemann.

Taylor, J., Blades, N. and Cassar, M. (2003) Report on results from review of existing preventive conservation strategies for organic materials. Deliverable D.1.1. WP1. Restricted report to the European Commission.

Taylor, J., Blades, N. and Cassar, M. (2004a) Evaluation report based on end-users review of WP2-3. Results from workshop. Deliverable D.6.1. WP6. Restricted report to the European Commission.

Taylor, J., Blades, N., Cassar, M., Grøntoft, T., Rentmeister, S. and Sommer-Larsen, A. (2006) Revised preventive conservation strategy including the early warning system. Deliverable D.6.2. WP6. Restricted report to the European Commission.

Thomson, G. (1978) The Museum Environment. London, Butterworths.

Thomson, G. (1986) The Museum Environment. 2nd edition. London, Butterworth-Heinemann.

6.2 References from Ch. 2.1.1

Ashley-Smith, J. (1999) Risk Assessment for Object Conservation. Oxford, Butterworth-Heinemann.

Ashley-Smith, J. (2000) Developing professional Uncertainty. In: *Tradition and Innovation: advances in conservation*. Ed. by: A. Roy and P. Smith. Melbourne, IIC. pp. 14-17.

Ashley-Smith, J., Derbyshire, A. and Pretzel, B. (2002) The continuing development of a practical lighting policy for works of art on paper and other objects types at the Victoria and Albert Museum. In: *ICOM-CC 13th Triennial meeting, Rio de Janeiro*. Ed. by: R. Vontobel, London, James and James. pp. 3-8.

Ashley-Smith, J., Umney, N. and Ford, D. (1994) Let's be honest – realistic environmental parameters for loaned objects. In: *Preventive Conservation: practice theory and research*. Ed. by: Roy et. al. London, IIC. pp. 69-72.

ASHRAE (2003) Applications Handbook (SI). Atlanta, ASHRAE. pp. 20.1-20.13.

Australia ICOMOS (1999) The Australia ICOMOS charter for the Conservation of Places of Cultural Significance (Burra charter). Australia ICOMOS.

Bacci, M., Picollo, M., Porcinai, S. and Radicati, B. (1997) Non-destructive spectrophotometry and colour measurements applied to the study of works of art. *Techne*, no. 5, 28-33.

Bacci, M., Picollo, M., Porcinai, S. and Radicati, B. (1999) Indoor environmental monitoring of colour changes of tempera-painted dosimeters. In: *ICOM-CC 12th Triennial, Lyon*. Ed. by: J. Bridgland. London, James and James. pp. 3-7.

Bacci, M., Cucci, C., DuPont, A.-L., Lavédrine, B., Loisel, C., Gerlach, S., Roemich, H. and Martin, G. (2005), LightCheck®, new disposable indicators for monitoring lighting conditions in museums. In: *ICOM-CC Committee for Conservation 14th Triennial Meeting, The Hague,* Ed. by: I. Verger. London, James and James. pp. 569-573.

Blades, N., Kruppa, D. and Cassar, M. (2002) Development of a web-based software tool for predicting the occurrence and effect of air pollutants inside museum buildings. In: *ICOM-CC 13th Triennial meeting, Rio de Janeiro*. Ed. by: R. Vontobel. London, James and James. pp. 9-14.

Bradley, S. (1996) Development of an Environmental Policy for the British Museum. In: *ICOM-CC 11th Triennial*, *Edinburgh.* Ed. by: J. Bridgland. London, James and James. pp. 8-13.

Bradley, S. (2005) Defining suitability of museum galleries by risk mapping. In: *ICOM-CC Committee for Conservation 14th Triennial Meeting, The Hague.* Ed. by: I. Verger, London, James and James. pp. 574-581.

Brimblecombe, P. (1990) The composition of museum atmospheres. *Atmospheric Environment*, *24B*, 1-8.

Brimblecombe, P. (1996) Pollution Studies, ENVIRONMENT Leather Project, Deterioration and Conservation of Vegetable Tanned Leather EV5V-CT94-0514, Protection and Conservation of The European Cuotural Heritage Research Report No. 6, European Commission, pp. 25-31.

Brokerhof, A., Luger, T., Ankersmit, B., Bergevoet, F., Schillmans, R., Schoutens, P., Muller, T., Kiers, J., Muething, G. and Waller, R. (2005) Risk Assessment of Museum Amstelkring: application to an historic building and its collections and the consequences for preservation management. In: *ICOM-CC Committee for Conservation 14th Triennial Meeting, The Hague*. Ed. by: I. Verger. London, James and James. pp. 590-596.

Bullock, L. and Saunders, D. (1999) Measurement of cumulative exposure using Blue Wool standards. In: *ICOM-CC 12th Triennial, Lyon*. Ed. by: J. Bridgland. London, James and James. pp. 21–26.

Cannon-Brookes, P. (1993) The 'Delta-plan' for the preservation of Cultural Heritage in the Netherlands. *Museum Management and Curatorship, 12,* 303-307.

Cassar, M. (1995) Environment Management: guidelines for museums and galleries. London, Routledge.

Cassar, M. and Oreszczyn, T. (1991) Environmental surveys in museums and galleries in the United Kingdom. *Museums Management and Curatorship, 10,* 385-402.

CIE (1995) Industrial colour-difference evaluation. CIE publication 116-1995. Vienna, Commission Internationale l'Eclairage.

Derbyshire, A. and Ashley-Smith, J. (1999) A proposed practical lighting policy for works of art on paper at the V&A. In: *ICOM-CC 12th Triennial meeting, Lyon.* Ed. by: J. Bridgland. London, James and James. pp. 38-41.

Dollery, D. (1994) A methodology of Preventive Conservation for a large, expanding and mixed archaeological collection. In: *Preventive Conservation: practice theory and research*. Ed. by: Roy et al. London, IIC. pp. 69-72.

Drysdale, L., Southall, A. and Cassar, M. (2000) European Preventive Conservation Strategy. In: *European Preventive Conservation Strategy Project*. Evtek, Vantaa. pp. 159-161.

Eden, P., Dungworth, N., Bell, N. and Matthews, G. (1998) A model for assessing preservation needs in libraries. British Library Research and Innovation Report 125, British Library.

Erhardt, D. (1988) Paper degradation: a comparison of industrial and archival concerns. In: *Paper preservation: Current issues and recent developments*. Ed. by: Philip Luner. Washington, TAPPI press. pp. 63-68.

Feller, R. (1978) Further studies on the international blue wool standards for exposure to light. In: *ICOM-CC 5th triennial, Zagreb.* 18/2/1-10.

Feller, R. and Johnson-Feller, R.M. (1978) Use of the International Standards Organization's blue wool standards for exposure to light. Preprints of the 6th AIC meeting, Fort Worth. pp. 73-80.

Graminski, E. L., Parks, E. J. and Toth, E. E. (1979) The Effects of Temperature and Moisture on the Accelerated Aging of Paper. In: *Durability of Macromolecular Materials*. Ed. by: R.K. Ed. by. American Chemical Society (ACS Symposium Series 95), Washington DC. pp 341-355.

Greeves, M. (2001) Risk management at the Fitzwilliam Museum, Cambridge. *Journal of Architectural Conservation, 7*, 67-79.

Grzywacz, C. (1993) Using passive sampling devices to detect pollutants in museum environments. In: *ICOM-CC 10th Triennial*, Washington. Ed. by: J. Bridgland. pp. 610-615.

Grzywacz, C.M. and Tennent, N. (1994) Pollution monitoring in storage and display cabinets: carbonyl pollutant levels in relation to artefact deterioration. In: *Preventive conservation: practice, theory and research*. Ed. by: Roy et al. London, IIC. pp. 165-170.

Henry, M. (2000) Suggested protocol for diagnostic monitoring in museums. Technical Note, J. Paul Getty Trust.

Holmberg, J.G. and Johansson, L. (1996) Preventive conservation in Swedish museums: technical museum storage room survey 1994-1995. In: *ICOM-CC 11th Triennial, Edinburgh.* Ed. by: J. Bridgland. London, James and James. pp. 41-47.

Johnsen, J.S. (1994) Surveying large collections of photographs for archival survival. In: *Preventive conservation: practice theory and research*. Ed. by: Roy et al. IIC. pp. 202-206.

Johnsen, J.S. and Bonde-Johansen, K. (2002) Condition survey and preservation strategies at the Danish Film Archive. In: *ICOM-CC 13th Triennial, Rio de Janeiro*. Ed. by: R. Vontobel. London, James and James. pp. 644-650.

Keene, S. (1991) Audits of care: a framework for collections condition surveys. In: *Storage.* Ed. by: M. Norman and V. Todd. UKIC. pp. 6-16.

Keene, S. (2002) Managing Conservation in Museums. 2nd edition. London, Butterworth-Heinemann.

Keene, S. and Orton, C. (1992) Measuring the condition of museum collections. In: *CAA91: Computer Applications and quantitative methods in archaeology*. Ed. by: G. Locke and J. Moffett. Oxford, British Archaeological Reports. pp. 163-166.

Kingsley, H. and Payton, R. (1994) Condition Surveying of large, varied stored Collections. *Conservation News, 54,* 8-10.

Koestler, R.J., Brimblecombe, P., Camuffo, D., Ginell, T.E., Leavengood, P., Petushkova, J., Steiger, M., Urzi, C., Verges-Belmin, V. and Warscheid, T. (1994) Group Report: How do external environmental factors accelerate change? In: *Durability and Change: the Science, Responsibility and Cost of Sustaining Cultural Heritage*. Ed. by: W.E. Krumbein, P. Brimblecombe, D.E. Cosgrove and S. Staniforth. Chichester, John Wiley and Sons. pp. 149-163.

Larsen, R. (Ed.) (1996) Deterioration and conservation of vegetable tanned leather. European Commission, Environment Leather Project, Research report no. 6.

Marcon, P. (1997) Decision support models for preventive conservation. In: *The Interface between Science and Conservation*. Ed. by: S. Bradley. British Museum Occasional paper no. 116. London, British Museum Press. pp. 143-151.

Martin, G. (1992) Development of a preventive conservation strategy and its implementation. In: *La Conservation Preventive*. Paris, ARAAFU. pp.41-46.

Martin G (1997) Assessing and monitoring the environment of cultural property. In: *The Interface between Science and Conservation*. Ed. by: S. Bradley. British Museum Occasional paper no. 116. London, British Museum Press. pp. 91-98.

Menegazzi, C. and Putt, N. (2000) Preventive conservation survey of European musems and services: results and commentary. In: *European Preventive Conservation Strategy Project.* Evtek, Vantaa. pp.174-197.

Michalski, S. (1990) An overall framework for preventive conservation and remedial conservation. In: *ICOM-CC 9th Triennial meeting, Dresden*. London, James and James. pp. 589-591.

Michalski, S. (1993) Relative Humidity: a discussion of correct/incorrect values. In: *ICOM 10th Triennial, Washington.* Ed. by: J. Bridgland. pp. 624-629.

Michalski, S. (1994) A systematic approach to preservation: description and integration with other museum activities. In: *Preventive conservation: practice, theory and research*. Ed. by: A. Roy and P. Smith. London, IIC. pp. 8-11.

Michalski, S. (2002) Double the life for each five-degree drop, more than double the life for each halving of relative humidity. In: *ICOM-CC 13th triennial, Rio de Janeiro.*Ed. by: R. Vontobel. London, James and James. pp. 66-72.

Moore, B.P. (1996) The conservation assessment survey as a long-range planning tool: a case study at the Peabody museum. In: *ICOM-CC 11th Triennial meeting, Edinburgh.* Ed. by: J. Bridgland. London. James and James. pp. 784-789.

Nara Document of Autenticity (1994) World Heritage Convention, 1-6th November, 1994, Nara, Japan, Agency for Cultural Affairs.

Netherlands Ministry of Welfare, Health and Cultural Affairs (1992) Deltaplan for the preservation of cultural heritage in the Netherlands. Fact sheet C-11-E-1992.

Newey, H.M., Bradley, S.M. and Leese, M.N. (1993) Assessing the condition of archaeological iron: an intercomparison. In: *ICOM 10th Triennial*, *Washington.* Ed. by: J. Bridgland. pp.786-791.

Odlyha, M. (1998) Characterisation of Cultural Materials by Measurement of the Physiochemical Properties. PhD thesis, University of London.

Odlyha, M., van den Brink, O. F., Boon, J.J., Bacci, M. and Cohen, N.S. (2002) Damage assessment of museum environments using paint-based dosimetry. In: *ICOM-CC 13th Triennial meeting, Rio de Janeiro.* Ed. by: R. Vontobel. London, James and James. pp. 73-79.

Odlyha, M., Wade, N., Wang, Q., Campana, R., Slater, J. M., Rhyl Svendsen, M., Padfield, T., De Santis, F., Smith, V. A., Bullock, L., Ferreira, E. S. B., Boon, J. J., Pratt, K. and Ormsby, B. (2005) Microclimate Indoor Monitoring: Damage Assessment for Cultural Heritage Preservation. In: *ICOM-CC Committee for Conservation 14th Triennial Meeting, The Hague.* Ed. by: I. Verger. London, James and James. pp. 670-678.

Orton, C. (1996) Markov models for museums. In: *Proceedings of the 23rd conference, Leiden, 1995, CAA*. Ed. by: H. Kamermans and K. Fennema. Published as: *Analecta Praehistorica Leidensia*, no. 28, 1996.

Orton, C. (2000) Sampling in Archaeology. Cambridge, Cambridge University Press.

Padfield, T. (1994) The Role of Standards and Guidelines: are they a substitute for understanding a problem of protection against consequences of ignorance? In: *Durability and Change: the Science, Responsibility and Cost of Sustaining Cultural Heritage*. Ed. by: W.E. Krumbein, P. Brimblecombe, D.E. Cosgrove and S. Staniforth. Chichester, John Wiley and Sons. pp. 191-200.

Pauk, S. and Porck, H. (1996) Land om Land. Verslag van de Bestudering van Identieke Boekenparen, die Onder Verschillende Omstandigheden Zijn Bewaard. The Hague, Koninklijke Bibliotheek.

Peacock, E. and Sæterhaug, R. (1996) Quantifying the Conservation Backlog: The Trondelag Project. In: *ICOM-CC 11th Triennial*, *Edinburgh*. Ed. by: J. Bridgland. London, James and James. pp. 7-79.

Porck, H. (2000) Rate of Paper Degradation: the predictive value of artificial aging tests. Amsterdam, Committee of Preservation and Access.

Pretzel, B. (2005) The RIBA project: a climate strategy for paper-based archives at the Victoria & Albert Museum. In: *ICOM-CC Committee for Conservation 14th Triennial Meeting, The Hague.* Ed. by: I. Verger. London, James and James. pp. 681-688.

Putt, N. and Menegazzi, C. (1999) ICCROM preventive conservation experiences in Europe. In: *ICOM-CC 12th Triennial, Lyon.* Ed. by: J. Bridgland. London, James and James. pp. 93-99.

Reilly, J., Nishimura, D. and Zinn, E. (1995) New Tools for Preservation: assessing long-term environmental effects on library and archives collections. Washington, Commission on Preservation and Access.

Sebera, D. (1994) Isoperms: an environmental tool. Washington, Committee on Preservation and Access.

Shenton, H. (1992) A conservation strategy for books at the Victoria and Albert Museum. In: *IPC Conference Papers, Manchester 1992. Ed. by:* S. Fairbrass. Leigh, Institute of Paper Conservation. pp.133-40.

Staniforth, S., Ballard, M. W., Caner-Saltik, E. N., Drewello, R., Eckmann, I-L., Krumbein, W. E., Padfield, T., Reddy, M. M., Schuller, M., Simon, S., Slavoshevskaya, L., Tennent, N. H. and Wolters, W. (1994) Group report: What are appropriate strategies to evaluate change and to sustain cultural heritage? In: *Durability and Change: the Science, Responsibility and Cost of Sustaining Cultural Heritage*. Ed. by: W.E. Krumbein, P. Brimblecombe, D.E. Cosgrove and S. Staniforth. Chichester, John Wiley and Sons. pp. 217-224.

Taylor, J. (2005) An integrated approach to risk assessment and condition surveys. *Journal of the American Institute for Conservation*, *44*, 127-141.

Taylor, J., Blades, N. and Cassar, M. (2004b) Evaluation of the rate of decay on selected organic objects in museums and historic buildings D.4.1. WP4. Restricted report to the European Commission.

Taylor, J. and Cassar, M. (2003) Profiling past environments in historic houses to inform future collections management. *Collections Review, 4,* 145-149.

Taylor, J. and Stevenson, S. (1999) Investigating Subjectivity within Collection Condition Surveys. *Journal for Museums Management and Curatorship*, *18,* 18-42.

Tennison, H., Van der Reyden, D., Tsai, F. W. and Parrish, M. (1996) An "Angel Project" of Dinosaur Proportions. *The Book and Paper Group Annual*, 15, 145-159.

Tétrault, J. (2003) Airborne Pollutants in Museums, Galleries, and Archives: Risk Assessment, Control Strategies and Preservation Management. Ottawa, Canadian Conservation Institute.

Thomson, G. (1978) The Museum Environment. London, Butterworths.

Thomson, G. (1986) The Museum Environment. 2nd edition. London, Butterworth-Heinemann.

Van der Reyden, D., Tennison, H. and Tsai, F.W. (1996) Publish then perish: The reclamation of a collection of scientific illustrations. *Restaurator, 17,* 104-115.

van Huis, E. (1992) Delta Plan workshop 21-23rd October 1992.

Venice charter (1964) International Charter for the Conservation and Restoration of Monuments and Sites.

Verling, E. and McParland, M. (2000) European Preventive Conservation Strategy. In: *European Preventive Conservation Strategy Project.* Evtek, Vantaa, pp. 50-55 and 118-123.

Waller, R. (1994) Conservation Risk Assessment: a Strategy for Managing Resources for Preventive Conservation. In: *Preventive conservation: practice theory and research*. Ed-by: A. Roy and P. Smith. London, IIC. pp. 12-16.

Waller, R. (2002) A Risk Model for Collection Preservation. In: *ICOM-CC 13th Triennial meeting, Rio de Janeiro*. Ed. by: R. Vontobel. London, James and James. pp. 102-107.

Waller, R. (2003) Cultural property risk analysis model: development and application to preventive conservation at the Canadian Museum of Nature. Ph.D. diss., University of Göteborg, Sweden.

Waller, R. and Michalski, S. (2005) A Paradigm Shift for Preventive Conservation, and a Software Tool to Facilitate the Transition. In: *ICOM-CC Committee for Conservation 14th Triennial Meeting, The Hague*. Ed. by: I. Verger. London, James and James. pp. 733-738.

Wiederkehr, R.R.V. (1984) The design and analysis of a sample survey of the condition of books in the Library of Congress. Library of Congress report. Washington, Library of Congress.

6.3 References from Ch. 2.2.2

Baer, N.S. and Banks, P.N. (1985) Indoor air pollution: Effects on cultural and historical materials. *The International Journal of Museum Management and Curatorship, 4*, 9-20.

Barrow, W.J. (1955) Manuscripts and Documents: their Deterioration and Restoration. Charlottesville, University of Virginia Press.

Blades, N. W., Bordass, W., Oreszczyn, T. and Cassar, M. (2000) Guidelines on Pollution Control in Museum Buildings. London, Museum Practice.

Brimblecombe, P. (1990) The composition of museum atmospheres. *Atmospheric Environment, 24B*, 1-8.

Bukovsky, V. (2000) The natural ageing of paper after exposure to daylight. *Restaurator, 21*, 229-237.

Cuttle, C. (1988) Lighting works of art for exhibition and conservation. *Lighting Research and Technology, 20*, 43-53.

Daniel, F., Fleider, F. and LeClerc, F. (1992) The behaviour of papers deacidified under pressure by Ethylmagnesium Carbonate as regards two kinds of Accelerated Aging: Wet heat and simulated pollution. In: *Papers of the Conference on Book and Paper Conservation*, Budapest, TAPPI. pp. 471-482.

Emsley, A.M. and Stevens, G.C. (1994) Kinetics and mechanisms of the low temperature degradation of cellulose. *Cellulose, 1*, 26-56

Erhardt, D. and Mecklenburg, M. (1994) Relative humidity re-examined. In: *Preventive conservation: practice theory and research.* Ed. by: A.Roy and P. Smith. London, IIC. pp. 32-38.

Grosjean, D., Whitmore, P.M., De Moor, C.P. and Cass, G.R. (1988) Ozone fading of organic colorants: Products and mechanism of the reaction of ozone with curcumin. *Environmental Science and Technology, 22*, 1357-1361.

Hansen, E.F., Lee, S.N. and Sobel, H. (1992) The effects of relative humidity on some physical properties of modern vellum: implications for the optimum relative humidity for the display and storage of parchment. *Journal of the American Institute for Conservation, 31*, 325-342.

Hatchfield, P.B. (2002) Pollutants in the Museum Environment - practical strategies for problem solving in design, exhibition and storage. London, Archetype Publications.

Havermans, J.B.G.A. (1995a) Environmental Influences on the Deterioration of Paper. Rotterdam, Barjesteh, Meeuwes & Co.

Havermans, J.B.G.A. (1995b) Effects of Air Pollutants on the Accelerated Aging of Cellulose-based materials. *Restaurator, 16,*209-233.

Kolar, J. and Strlic, M. (Eds.) (2005) Ageing and stabilisation of paper. National and University Library, Ljubljana.

Michalski, S. (2002) Double the life for each five-degree drop, more than double the life for each halving of relative humidity. *ICOM-CC 13th triennial, Rio de Janeiro*. Ed. by: R. Vontobel. London, James and James. pp. 66-72.

Pauk, S. and Porck, H. (1996) Land om Land. Verslag van de Bestudering van Identieke Boekenparen, die Onder Verschillende Omstandigheden Zijn Bewaard. The Hague, Koninklijke Bibliotheek.

Reilly, J., Nishimura, D. and Zinn, E. (1995) New Tools for Preservation: assessing long-term environmental effects on library and archives collections. Washington, Commission on Preservation and Access.

Saunders, D. and Kirby, J. (1994) Wavelength-dependent fading of artists' pigments. In: *Preventive Conservation*: *practice theory and research.* London, IIC. pp. 190-194.

Schaeffer, T.T. (2001) Effects of Light on Materials in Collections (Data on Photoflash and Related Sources). Los Angeles, Getty Publications.

Sebera, D. (1994) Isoperms: an environmental tool. Washington, Committee on Preservation and Access.

Thomson, G. (1994) The Museum Environment. 2nd edition. Oxford, Butterworth-Heinemann.

Timar-Balazsy, A. and Eastop, D. (1998) Chemical Principles of Textile Conservation. Oxford, Butterworth-Heinemann.

Zou, X., Uesaka, T. and Gurnagul, N. (1996) Prediction of Paper Permanence by Accelerated Ageing. Part 1: Kinetic Analysis of the Ageing Process. *Cellulose, 3*, 243-267.

6.4 References from Ch. 2.2.3

Bacci, M., Cucci, C., Dupont, A.-L., Lavédrine, B., Picollo, M. and Porcinai, S. (2003) Disposable indicators for monitoring lighting conditions in museums. *Environmental Science and Technology, 37,* 5687-5694.

Berre, B. and Lala, D. (1989) Investigation on photochemical dosimeters for ultraviolet radiation. *Solar Energy, 5,* 405-416.

Bullock, L and Saunders, D. (1999) Measurement of cumulative exposure using Blue Wool standards. In: *ICOM-CC 12th Triennial, Lyon*. Ed. by: J. Bridgland. London, James and James. pp. 21–26.

Dahlin, E., Grøntoft, T., Rentmeister, S., Calnan, C., Czop, J., Howell, D., Pitzen, C., Sommer-Larsen, A. (2005) Development of an early warning dosimeter for assessing deterioration of organic materials indoor in museums, historic buildings and archives. In: *ICOM-CC Committee for Conservation 14th Triennial Meeting, The Hague*. Ed. by: I. Verger. London, James and James. pp. 617-624.

Larsen, R. (Ed.) (1996) *Deterioration and conservation of vegetable tanned leather*, European Commission, Environment Leather Project, Research report no. 6.

Leissner, J, Beuschlein, S., Pilz, M., Martin, G., Blades, N. and Redol, P. (1996) Assessment and monitoring the environment of cultural property. Final report 1993-1996. Brussels, EC Environment Programme (Contract number EV5V-CT92-0144 AMECP).

Mills, J.S. and White, R. (1994) The organic chemistry of museum objects. 2nd Edition. Oxford, Butterworth-Heinemann.

Oddy, W.A. (1973) An unsuspected danger in display. *Museums Journal, 73,* 27-28.

Rentmeister, S., Hanko, M. and Heinze, J. (2005) Novel early warning sensors for museum, historic buildings and archives by determination of the gaseous pollutants nitrogen dioxide, ozone and sulphur dioxide. *Museum Aktuell, 117,* 23-26.

Sebera, D. (1994) Isoperms: an environmental tool. Washington, Committee on Preservation and Access.

Tétrault, J. (2003) Airborne Pollutants in Museums, Galleries, and Archives*:* Risk Assessment, Control Strategies and Preservation Management. Ottawa, Canadian Conservation Institute.

Zinn, E., Reilly, J. M., Adelstein, P. Z. and Nishimura, D. W. (1994) Air pollution effects on library microforms. In: *Preventive Conservation Practice, Theory and Research. Preprints on the Contributions to the Ottawa Congress, 12-16 September 1994.* Ed. by: Roy, A. and Smith, P. London, IIC, pp. 195-201.

6.5 References from Ch. 2.2.4

Brimblecombe, P. (1990) The composition of museum atmospheres. *Atmospheric Environment, 24B*, 1-8.

Brimblecombe, P., Blades, N., Camuffo, D., Sturado, G., Valentino, A., Gysels, K., Van Grieten, R., Busse, H.-J., Kim, O., Ulrych, U. and Wieser, M. (1999) The Indoor Environment of a Modern Museum Building, the Sainsbury Centre for Visual Arts, Norwich, UK. *Indoor Air, 9*, 146-164.

Camuffo, D., Van Grieken, R., Busse, H.-J., Sturaro, G., Valentino, A., Bernardi, A., Blades, N., Shooter, D., Gysels, K., Deutsch, F., Wieser, M., Kim, O. and Ulrych, U. (2001) Environmental monitoring in four European museums. A*tmospheric Environment*, *35*, Supplement No. 1, pp. S127-S140.

Cass, R.G., Nazaroff, W.W., Tiller, C. and Whitmore, P.M. (1991) Protection of works of art from damage due to atmospheric ozone. *Atmospheric Environment, 25A*, 441-451.

Chaloulakou, A. and Mavroidis, I. (2002) Comparison of indoor and outdoor concentrations of CO at a public school. Evaluation of an indoor air quality model. *Atmospheric Environment, 36*, 1769-1781.

Chen, F., Yu, S.C.M. and Lai, A.C.K. (2006) Modelling particle distribution and deposition in indoor environments with a new drift–flux model. *Atmospheric Environment*, *40*, 357-367.

Dimitropoulou, C., Ashmore, M.R., Byrne, M.A. and Kinnersley, R.P. (2001) Modeling of indoor exposure to nitrogen dioxide in UK. *Atmospheric Environment, 35*, 269-279.

Druzik, J.R., Adams, M.S., Tiller, C. and Cass, G.R. (1990) The measurement and model predictions of indoor ozone concentrations in museums. *Atmospheric Environment, 24A*, 1813-1823.

Ekberg, L.E. (1994) Outdoor Air Contaminants and Indoor Air Quality under Transient Conditions. *Indoor Air, 4*, 189-196.

Fan, Y. (1995) CFD modelling of the air and contaminant distribution in rooms. *Energy and Buildings*, *23,* 33-39.

Gysels, K., Delalieux, F., Deutsch, F., Van Grieken, R., Camuffo, D., Bernardi, A., Sturaro, G., Busee, H-J. and Wieser, M., (2004) Indoor environment and conservation in the Royal Museum of Fine Arts, Antwerp, Belgium. *Journal of Cultural Heritage, 5*, 221-230.

Hayes, S.R. (1989) Estimating the effect of being indoors on total personal exposure to outdoor air pollution. *Journal of the Air Pollution Control Association, 39*, 1453-1461.

Hayes, S.R. (1991) Use of an indoor air quality model (IAQM) to estimate indoor ozone levels. *Journal of the Air & Waste Management Association, 41*, 161-170.

Jones, A.P. (1999) Indoor air quality and health. *Atmospheric Environment, 33*, 4535-4564.

Nazaroff, W.W. and Liu, De-Ling (2001) Modeling pollutant penetration across building envelopes. *Atmospheric Environment, 35*, 4451 - 4462.

Nazaroff, W.W. and Cass, G.R. (1986) Mathematical modelling of chemically reactive pollutants to indoor air. *Environmental Science and Technology, 20*, pp. 924-934.

Papakonstantinou, K.A., Kiranoudis, C.T. and Markatos, N.C. (2000) Mathematical modeling of environmental conditions inside historical buildings. The case of the archaeological museum of Athens. *Energy and Buildings 31*, 211–220.

Spengler, J.D. and Sexton, K. (1983) Indoor air pollution: a public health perspective. *Science 221*, 9-17.

Salmon, L.G., Cass, G.R. and Bruckman, J.H. (2000) Ozone exposure in the historic central district of Krakow, Poland (2000). *Atmospheric Environment, 34*, 3823-3832.

Thatcher, T.L. and Layton, D.W. (1994) Deposition, resuspension, and penetration of particles within a residence. *Atmospheric Environment, 29*, 1487-1497.

6.6 References from Ch. 2.3

Berre, B. and Lala, D. (1989) Investigation on photochemical dosimeters for ultraviolet radiation. *Solar Energy, 5*, 405-416.

Dahlin, E., Grøntoft, T., Rentmeister, S., Calnan, C., Czop, J., Howell, D., Pitzen C., Sommer-Larsen, A. (2005) Development of an early warning dosimeter for assessing deterioration of organic materials indoor in museums, historic buildings and archives. In: *ICOM-CC Committee for Conservation 14th Triennial Meeting, The Hague.* Ed. by: I. Verger. London, James and James, pp. 617-624.

Rentmeister, S., Hanko, M. and Heinze, J. (2005) Novel early warning sensors for museum, historic buildings and archives by determination of the gaseous pollutants nitrogen dioxide, ozone and sulphur dioxide. *Museum Aktuell, 117*, 23-26.

Wypych, G. (1995) Handbook of Material Weathering. 2nd edition. ChemTec publishing, Toronto.

Hulanicki, S. and Glab, S. (1978) Redox indicators. Characteristics and applications. *Pure and Applied Chemistry*, *50*, 463-498.

Lipari, F. (1984) New solid-sorbent method for ambient nitrogen dioxide monitoring. *Analytical Chemistry*, *56*, 1820-1826.

Lambert, J.L., Paukstelis, J.V. and Chiang, Y.C. (1989) 3-Methyl-2-benzothiazolinone acetone azine with 2-phenylphenol as a solid passive monitoring reagent for ozone. *Enviromental Science and Technology*, *23*, 241-243.

Ohm, R.F. (1993) Review of antiozonants. *Rubber World*, *208*, 18-22.

Cataldo, F. (1996) On the reaction of ozone with beta-carotene, a naturally occurring polyene. *Polymer Degradation and Stability*, *53*, 51-56.

Ralfs, M. and Heinze, J. (1997) Disposable optochemical sensor for the determination of chlorine concentrations in the ppb-range. *Sensors and Actuators B: Chemical*, *44*, 257-261.

Alexy, M., Voss, G. and Heinze, J. (2005) Optochemical sensor for determining ozone based on novel soluble indigo dyes immobilised in a highly permeable polymeric film. *Analytical and Bioanalytical Chemistry*, 382, 1628–1641.

Alexy, M., Hanko, M., Rentmeister, S. and Heinze (2006) Disposable optochemical sensor chip for nitrogen dioxide detection based on oxidation of *N,N′*-diphenyl-1,4-phenylenediamine. *Sensors and Actuators B: Chemical, 114*, 916-922.

Hanko, M., Rentmeister, S. and Heinze (2004) Optochemischer Sensor zum Nachweis von SO_2. In: *Jahresbericht des Freiburger Materialforschungszentrum*. Freiburg, Freiburger Materialforschungszentrum. pp. 91-94.

Hanko, M. (2003) Untersuchungen über den Einsatz von Polymeren als Farbstoffmatrix in optochemischen Frühwarnsensoren zur Analyse von Schadgasen in Innenraumluft. Diplomarbeit. Freiburg.

Mark, H.F., Gaylord, N.G. and Bikales, N.M. (1968) *Encyclopedia of Polymer Science and Technology*, *9*, 794-806.

Vieth, W.R. (1991) Diffusion in and through polymers : principles and application. München, Hanser Gardner.

Mitchell, J.K. (1830) On the penetrativeness of fluids. *American Journal of the medical sciences*, *13*, 36-67.

Fick, A. (1855) Über diffusion. *Annalen der Phyik.und Chemie,94,* 59-86.

Wijmans, J.G. and Baker, R.W. (1995) The solution-diffusion model: a review. *Journal of Membrane Science*, *107*, 1-21.

6.7 References from Ch. 2.4

Mills, J.S. and White, R. (1994) The organic chemistry of museum objects. 2nd Edition. Oxford, Butterworth-Heinemann.

Thomson, G. (1986) The Museum Environment. 2nd edition. London, Butterworth-Heinemann.

Taylor, J., Blades, N. and Cassar, M. (2004b) Evaluation of the rate of decay on selected organic objects in museums and historic buildings D.4.1. WP4. Restricted report to the European Commission.

6.8 References from Ch. 2.5

Camuffo, D., Van Grieken, R., Busse, H.-J., Sturaro, G., Valentino, A., Bernardi, A., Blades, N., Shooter, D., Gysels, K., Deutsch, F., Wieser, M., Kim, O. and Ulrych, U. (2001) Environmental monitoring in four European museums. *Atmospheric Environment*, *35*, Supplement No. 1, S127-S140.

Dahlin, E., Grøntoft, T., Henriksen, J.F., Rentmeister, S., Hanko, M., Heinze, J., Taylor, J., Blades, N., Marshall, S. and Hallett, K. (2005) Report on assessment of deterioration of EWO dosimeters and silk and paper samples after exposure in 10 different European Museums. D. 3.2. Restricted report to the European Commission.

EU project IMPACT (2004) Final report, Contract No. EVK4-CT-2000-00031.

Grøntoft, T., Henriksen J. F., Dahlin, E., Lazaridis, M., Czop, J., Sommer-Larsen, A., Hallett, K., Calnan, C., Pitzen, C. and Cassar, J.A. (2005 a) Sensor and environmental data from the field test programme. Deliverable no. D. 3.1, WP 3. Restricted datafile report to the European Commission.

Nazaroff, W.W. and Liu, D.-L. (2001) Modeling pollutant penetration across building envelopes. *Atmospheric Environment*, *35*, 4451-4462.

Simpson, D., Fagerli, H., Jonson, J.E., Tsyro, S. and Wind, P. (2003) Transboundary Acidification, Eutrophication and Ground Level Ozone in Europe PART I. Unified EMEP Model Description. EMEP Status Report 1/2003. Oslo, Norwegian Meteorological Institute. URL: http://www.emep.int/publ/reports/2003/emep_report_1_part1_2003.pdf

Weschler, S.J., Shields, H.C. and Naik, D.V. (1994) Indoor Chemistry Involving O_3, NO and NO_2 as Evidenced by 14 Months of Measurements at a Site in Southern California. *Environmental Science and Technology,* 28, 2120-2132.

6.9 References from Ch. 2.7

Ashley-Smith, J. (1999) Risk Assessment for Object Conservation. Oxford, Butterworth-Heinemann.

Bradley, S. (1996) Development of an Environmental Policy for the British Museum. In: *ICOM-CC 11th Triennial, Edinburgh.* Ed. by: J. Bridgland. London, James and James. pp. 8-13.

Cannon-Brookes, P. (1993) The 'Delta-plan' for the preservation of Cultural Heritage in the Netherlands. *Museum Management and Curatorship, 12,* 303-307.

CIE (1995) Industrial colour-difference evaluation. CIE publication 116-1995. Vienna, Commission Internationale l'Eclairage.

Havermans, J.B.G.A. and Steemers, T.A.G. (2005) Air pollution and its prevention. In: *Ageing and stabilisation of paper.* Ed. by: Kolar, J. and Strlic, M. National and University Library, Ljubljana. pp. 165-179.

Henry, M. (2000) Suggested protocol for diagnostic monitoring in museums. Technical Note, J. Paul Getty Trust.

Keene, S. (1991) Audits of care: a framework for collections condition surveys. In: *Storage.* Ed. by: M. Norman and V. Todd. UKIC. pp. 6-16.

Larsen, R. (Ed.) (1996) Deterioration and conservation of vegetable tanned leather. European Commission, Environment Leather Project, Research report no. 6.

Michalski, S. (1994) A systematic approach to preservation: description and integration with other museum activities. In: *Preventive conservation: practice, theory and research*. Ed. by: A. Roy and P. Smith. London, IIC. pp. 8-11.

Putt, N. and Häyhä, H. (2002) European preventive conservation strategy project: A project report. Vanttaa, Evtek.

Taylor, J. (2005) An integrated approach to risk assessment and condition surveys. *Journal of the American Institute for Conservation, 44,* 127-141.

Taylor, J. Blades, N. and Cassar, M. (2003) Report on results from review of existing preventive conservation strategies for organic materials. Deliverable D.1.1. WP1. Restricted report to the European Commission.

Thomson, G. (1986) The Museum Environment. 2nd edition. London, Butterworth-Heinemann.

Waller, R. (1994) Conservation Risk Assessment: a Strategy for Managing Resources for Preventive Conservation. In: *Preventive conservation: practice theory and research.* Ed. by: A. Roy and P. Smith. London, IIC. pp. 12-16.

Waller, R. (1999) Internal pollutants, risk assessment and conservation priorities. In: *ICOM-CC 12th Triennial, Lyon*. Ed. by: J. Bridgland. London, James and James. pp. 113-118.

Waller, R. (2003) Cultural property risk analysis model: development and application to preventive conservation at the Canadian Museum of Nature. Ph.D. diss., University of Göteborg, Sweden.

6.10 Reference from Ch. 2.8

Thomson, G. (1986) The Museum Environment. 2nd edition. London, Butterworth-Heinemann.

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ABSTRACT
The main aim of the MASTER project was the development of an early warning dosimeter system for organic objects (EWO dosimeters) that could provide a relatively cheap and easy way for museums and other cultural heritage institutions, as a first step, to evaluate the quality of the environment they provide for organic materials.

Two related aims of the MASTER project were to review existing preventive conservation strategies for organic materials and to develop a new and refined preventive strategy based on an early warning system. This work was carried out by reviewing preventive conservation literature with special reference to organic materials, questionnaires to heritage institutions and through an end-user workshop exploring the views of preventive conservation experts and end-users to influence strategic developments.

By introducing this new preventive conservation strategy, the sustainable exploitation of cultural property can be enhanced.

NORWEGIAN TITLE

KEYWORDS		
MASTER	EWO-dosimeter	Cultural heritage

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