PRESENTATION IN ORIGINAL CONTEXTS VIA MICROCLIMATES

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ABSTRACT
English Heritage's presentation policy is to display more of its extensive collections on the sites with which they are associated. Many of the buildings have suffered the ravages of time and have far from ideal environments. A series of climate-controlled enclosures has been developed to allow safe exhibition of artefacts, while providing access to visitors who would be unlikely to visit a major museum.

Archaeological metals deteriorate rapidly in the damp environments inside many historic buildings and a low-maintenance showcase design, incorporating silica gel, has been developed and tested extensively. With a combination of careful showcase design, comprehensive testing and refitting and mechanical conditioning, vulnerable tapestries, parchment documents, panel paintings and leather have been provided with closely controlled environments in damp, widely fluctuating buildings. Microclimate frames have been developed and evaluated over 10 years to protect sensitive panel paintings and prints in aggressive environments.

INTRODUCTION

A significant proportion of the UK population visits heritage sites, but not museums. In 2006, 67.8–68.2% of the adult population of England visited heritage sites [1], compared to 47% who had visited museums, libraries and archives [2].

English Heritage holds in trust collections in excess of 500,000 artefacts, the largest proportion of which are the significant finds retained from archaeological excavations at the 403 sites for which it is responsible. The collections also include 2400 paintings, 1200 pieces of furniture and over 1000 sculptures. English Heritage's presentation policy aims to display more of this material at its original site in context.

The development of low-cost measurement methods for air exchange rates (AER), combined with leak detection to guide improvements for those showcases, can reliably produce cases meeting AER specifications [3]. Combined with confirmation of equations to allow modelling of the relative humidity (RH) inside showcases, this guarantees the environmental performance of such cases [4]. This has allowed safe display of a wide range of artefacts in rooms with extremely aggressive environments, facilitating access to very large numbers of people who would not enjoy this material in a museum context.

ARCHAEOLOGICAL METALS

During burial, reaction with chlorides can make archaeological iron and copper alloys extremely sensitive to ambient RHs. Bronze disease will occur above 42% and some archaeological iron is sensitive to RHs above 16%, with dramatic increases in deterioration rate at 30% and very significant electrochemical corrosion occurring above 50% [5]. The high ventilation rates and damp masonry of many buildings within English Heritage's estate lead to high internal RHs, with many rooms exceeding 80% for much of the year. Iron and copper alloys are at the greatest risk when archaeological collections are presented at these sites.

A standard showcase has been developed to allow the provision of a low RH atmosphere (less than 30% was the aim), using passive methods for in excess of six months [6]. Many historic sites do not have ready access to power and the wide geographic dispersion of English Heritage sites and limited conservation resources mean two staff visits a year are the most that can be sustained. Details of the design principles are described in Appendix 1. A cross-section of this showcase is shown in Fig. 1.

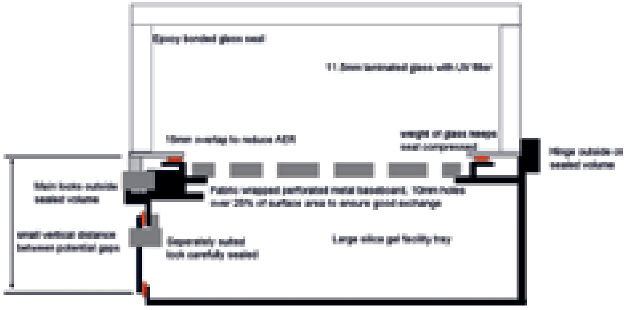

Fig. 1 Cross-section of design for low RH showcase with relevant features described.

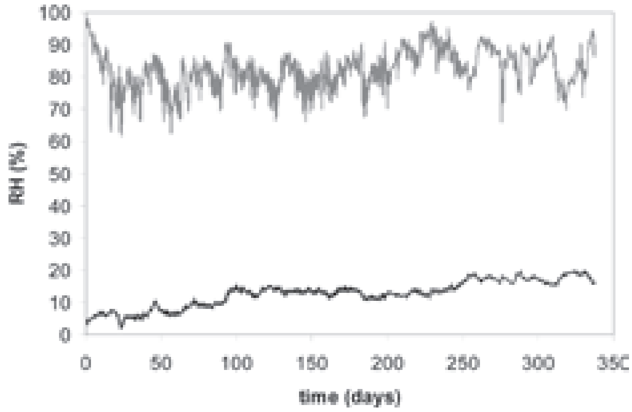

Fig. 2 Performance of low RH showcase, atmosphere below 20% is maintained for almost one year.

Over 30 such cases have now been installed at nine different sites and careful quality control (all cases have their air exchange rate tested as they are installed) has meant all the cases have AERs of less than 0.4 day^{-1} and the RH is consistently controlled below 30%. Fig. 2 shows the room RH and RH inside a representative case at Pevensey Castle.

Mechanical Dehumidification for Copper Alloys

A recent display installed in Yarmouth Castle, Isle of Wight included latten (copper alloy) and bone artefacts recovered from a wreck, probably of the *Santa Lucia*. A large vertical case was required for the display. This design is difficult to seal tightly and an AER of 6.7 day^{-1} was measured, making control with silica gel extremely difficult. RH gradients have been observed in such cases when control is attempted with silica gel. Internal fibre optic lighting was also required to spare the important historic fabric of the castle from installation of room lighting. The temperature gain from the fibre optic light source further drives air exchange. Since electricity had been fitted under the non-historic wooden flooring, a dehumidifier was installed to control the case environment. A RH range of 35–42% was selected to balance retarding bronze disease in the latten and excessive drying of the bone comb, also on display. The dehumidifier selected was a Munters MG50. Working on the dual air stream principle, this unit does not condense water, which would require constant emptying or a drain. It also works efficiently at the low

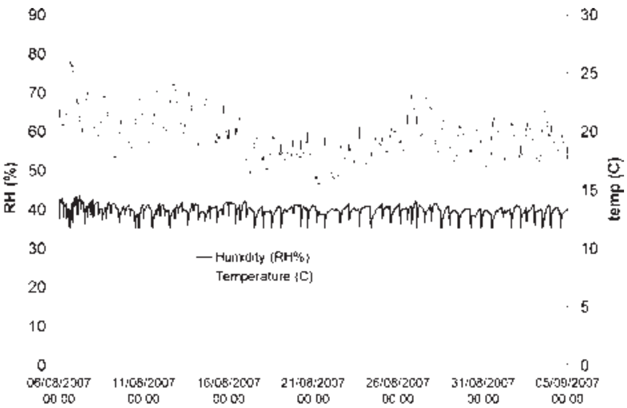

Fig. 3 Performance of dehumidifier controlled showcase at Yarmouth Castle.

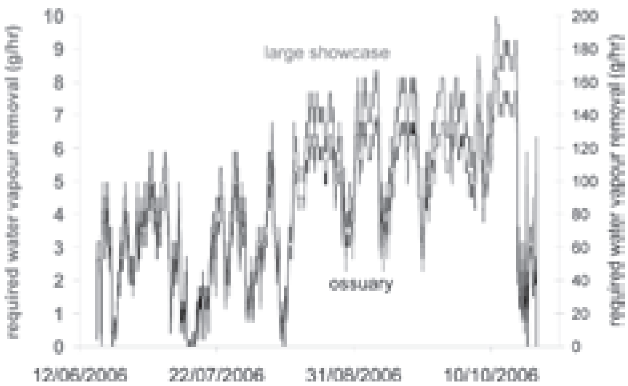

Fig. 4 Dehumidification requirements for control below 65% for large showcase and ossuary at St Peter's, Barton-upon-Humber.

temperatures sometimes experienced in March on opening the castle. The environment achieved inside the case is shown in Fig. 3. The high leakage rate of the case and significant overcapacity of the dehumidification led to characteristic RH cycles. Attempts to improve the sealing of the case and baffle the dehumidifier output are under way to reduce this effect.

Finding compromise RH conditions for mixed collections is a significant challenge in preventive conservation. Interpretation of a collection often requires objects of dissimilar materials to be displayed together to facilitate intellectual access. Archaeological metals are perhaps the most extreme example of this due to their very low RH requirements.

HUMAN REMAINS

Human remains from archaeological excavations at the deconsecrated church of St Peter's Church, Barton-upon-Humber, have formed an incredibly important study collection for osteoarchaeology since the 1950s. The spread of dates, sexes and ages of the skeletons has provided an unparalleled study set. A project to interpret this in the church and install an ossuary in the organ chamber, to store safely the 3000 remains and allow study access, was completed in 2007. In both spaces the high RH presented a mould risk, particularly in the still air of showcases/storage boxes. The temperature and RH in both spaces was monitored prior to the project, to determine the required dehumidification load to achieve 65% RH, either in the organ chamber or inside showcases, with air exchange rates below two per day. The amount of air ingressing the enclosure was calculated for one-hour intervals using the air exchange rate and volumes. The difference in absolute humidity between the room and the enclosure at the same temperature and 65% RH was calculated and combined with the amount of air ingressing, to calculate the amount of water vapour that would need to be removed from the enclosure volume to keep the RH below 65%. Results for the largest showcase and the ossuary are shown in Fig. 4.

The organ chamber was made airtight and the RH was controlled to 65% with a Munters MG50 dehumidifier with a high specification controller. Its efficiency at low temperatures was essential in the unheated space. The roller racking was deliberately placed against internal walls, with the stairs and researchers' desk located against the single external wall of the chamber. This arrangement was to prevent condensation occurring in the storage boxes due to proximity to the cold wall. Monitoring confirmed the adequate performance of the dehumidifiers when the exhibition opened in 2007.

There was concern that the light entering the space may cause surface heating to the artefacts, particularly the bones. St Peter's has several stained glass windows and the application of a neutral density film, to control light ingress, was not straightforward because of these. Preliminary work has shown some acceleration of the deterioration processes of certain types of glasses from the application of polymer films. Unfortunately this has not yet been contextualized by comparison with natural ageing rates, despite indications in a preliminary publication that this work was under way and would be presented [7].

The showcase glass includes a laminated ultraviolet (UV) film, protecting the bone and wooden coffin artefacts. No significant thermal gain was observed in the monitoring from the showcases. However, there was concern that surface heating of the bones could reduce their surface humidity to unacceptable levels and lead to deterioration. Many of the bones are stained black from tannic acid leaching out of their oak coffins, decreasing their albedo and increasing their propensity to heat under illumination. The surface temperature of bones in the showcase suffering illumination from the south-facing windows was measured with Pt 1000 surface resistance probes. The probes were tied onto the bone to ensure good thermal contact, with one probe illuminated and the second positioned on the dark side of the bone. Air temperature and RH were monitored directly adjacent to the bone, as were the illumination levels. The surface RH was calculated from the absolute humidity and surface temperature, as described by Schellen [8]. The monitoring, Fig. 5, showed that although the bones did suffer from photo-thermal heating, the surface RHs were well above the 35% that has been recommended for storage of such material [9].

These three solutions have allowed dramatically enhanced access to over 10000 objects for well over 250000 persons per year. The objects were previously in storage with only very limited access via appointment.

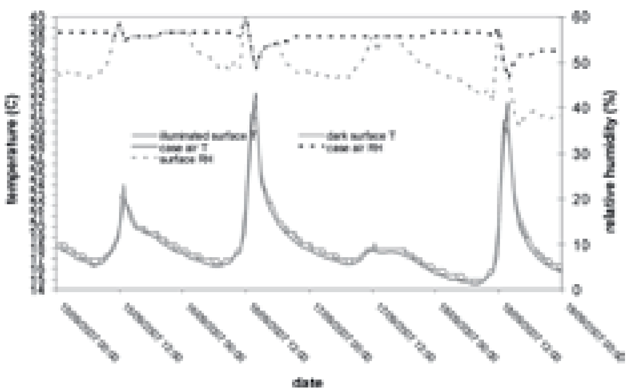

Fig. 5 Surface temperatures and RHs of bones illuminated through un-filmed windows at St Peter's, Barton-upon-Humber.

ELIZABETH AND DUDLEY EXHIBITION AT KENILWORTH CASTLE

Kenilworth Castle was the seat of the Earls of Leicester. Robert Dudley entertained Queen Elizabeth I there in 1575. The castle was rendered untenable in 1649 following the English Civil War, but Leicester's gatehouse was inhabited into the 1920s and fell into disrepair after this date. A major project was completed in 2006 to conserve the building and present the two lower floors as historic interiors and install a major exhibition on the top floor. Significant loan items formed part of the exhibition and very close environmental conditions were imposed for the loans, as befits such important items. Several of the lending institutions imposed different RH conditions. A strategy of controlling the showcase environments was adopted. A period of two years' monitoring of the environment in the gatehouse prior to the project showed the RH to be generally high and to fluctuate greatly. This environment would be classed as level D under the system developed by Michalski for the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) [10]. The marketing in the UK of a close-control RH conditioning system for showcases, (Miniclima EB08 and 09) appeared to present a better solution than coupled dehumidifiers and humidifiers for this exhibition. However, the unit needed careful evaluation to ensure it could provide an adequate level of control. The performance of the unit is also limited by the AER of the showcase in which it is installed, and a specification would need to be developed to ensure the loan conditions could be met. A unit was purchased and tested extensively in a showcase installed in the foyer of English Heritage headquarters building. This space had external doors that were frequently open and had an environment not dissimilar to that expected in the gatehouse after the conservation works to the building. The unit was run and closely monitored for 18 months. The amount of water produced or consumed was also measured to estimate the maintenance load required when installed. These units were first installed in the UK in the Post Office Museum, three years before this work. The museum was approached, and kindly allowed AER measurements on its showcases and access to its environmental monitoring records to help develop the showcase specification. Calculations were also undertaken in a similar manner to the dehumidification load to assess the maximum AER that a unit could be expected to control. A specification of 1.0 day^{-1} was developed, incorporating a good safety factor to account for wear of the showcases.

The return of an armorial tapestry of the Earls of Leicester, commissioned *c.* 1570 for Elizabeth I's apartments at Kenilworth, was arranged by loan from Glasgow Museums. English Heritage has funded conservation of a second tapestry from the pair, to be displayed in two years when the first is returned to Glasgow. The large size of the object, 3 × 2.5 m, required a large case, and the AER specification was challenging. A prolonged discussion on the design delivered a case that exceeded the specification (0.2 day^{-1}).

All of the showcase AERs were tested as they were built on site, and leak-tested to determine where the sealing could be improved. One showcase had to be rebuilt three times to meet the specification, and most needed some refitting. LED lighting was used in some cases to reduce any heating that would increase AER. Fibre optic light sources generate very significant temperatures and isolating them from the case is not a trivial exercise, as the length of the fibre optic cables is limited.

Calculations were undertaken with the AERs to determine how much 'PROSorb' silica gel needed to be added to the showcases to give 20 days from a conditioning failure to exceeding the loan RH conditions. A figure of 8 kg.m^{-3} was calculated and added to each showcase [4]. A Meaco radio telemetry system was installed to monitor the temperature and RHs inside the showcases and also the light levels. High precision Rotronic 'Hygroclip' probes were used to ensure data integrity. The system was connected to the English Heritage network to allow remote viewing of the data and alarming via any site, office or secure remote access.

Since the loan agreements precluded access to the showcases without a member of the lending institution being present, airtight fittings were designed for both the Miniclima control sensors and the Rotronic Hygroclip sensors used for the monitoring system. These allowed them to be removed from the showcases for maintenance and calibration without opening the cases.

The conditions achieved in the showcases are tabulated in Table 1. The majority of the cases easily met the loan specifications. The tapestry case initially showed short-lived RH peaks around 4 p.m. on most days, taking it out of specification, see Fig. 6. No obvious temperature perturbation was associated with these RH changes. Sunlight had been observed to strike the plinth containing the Miniclima unit at around this time in the afternoon during installation, before the blinds were lowered. It was postulated that the sun was heating the blind and although visible light was kept below 200 lux, infrared emission from the heated blind was heating the dark brown plinth. The surface temperature was measured on the outside and inside of the plinth using Pt 1000 sensors and a SR007 datalogger, and the internal air temperature inside the plinth was monitored with a Meaco transmitter. The external temperature of the plinth was observed to rise dramatically by almost 4ºC at the expected time. This was followed several minutes later by a smaller temperature rise on the internal surface and then by a rise in the air temperature inside the plinth. This temperature rise reduces the efficiency of the Peltier unit used for dehumidification in the Miniclima and the RH in the case rises. The problem was solved by adding two fans to the plinth casing to ensure sufficient air-flow to remove the heat swiftly. This work was undertaken on 4 September 2006 and the improvement in the conditions is clear in Fig. 6.

REDUCTION OF POLLUTION DEPOSITION IN PRINT FRAMES

Prints often have an intimate association with a place. Glazed framing is almost universally used to protect prints from the effects of physical damage, fluctuating RH, dust and pollutant gases. The very high ventilation rates of some historic properties, coupled with high levels of industrial pollution, pose a much higher risk than that present in many galleries. Chiswick

Table 1 Performance of conditioned showcases in Kenilworth Elizabeth and Dudley Exhibition.

Case	*Materials present*	*Loan Conditions*			*Amount of time within conditions (%)*	*Environment classification according to ASHRAE*
		RH (%)	*T (ºC)*	*Light (lux)*		
Tapestry		45–55	19–23	50	99.7	AA
Easel paintings and prints		45–55		50	100	A
Letters	Paper and parchment	45–60	19–21	50	100	AA
Boots and prints	Leather and paper	54–58	19–23	200	100	AA
Sweetbox	Silver and gold	40–60	19–23	300	100	A
Room		40–87				D

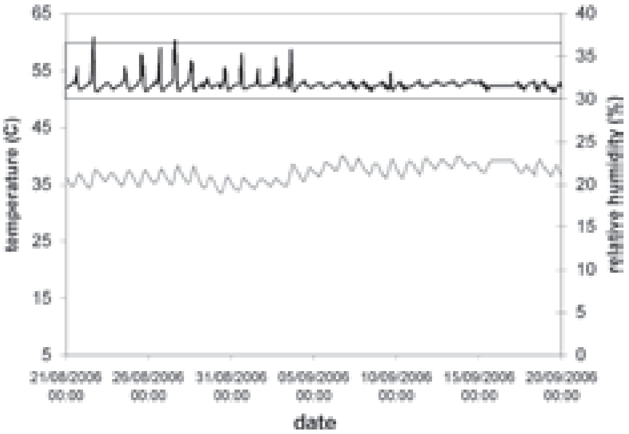

Fig. 6 Performance of tapestry showcase in Leicester's Gatehouse at Kenilworth Castle, before fitting of additional fan.

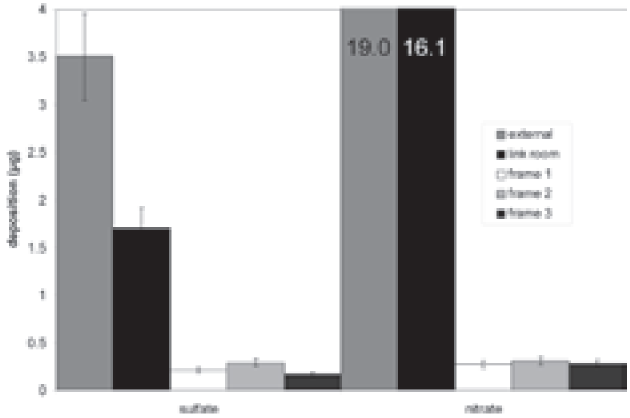

Fig. 8 Protection of print frames against pollution deposition in link building at Chiswick House.

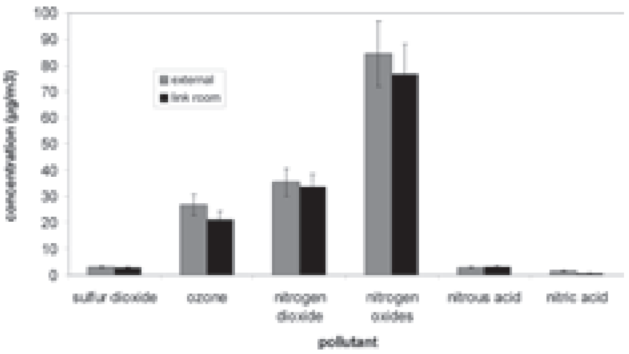

Fig. 7 Pollution ingress into link building at Chiswick House.

House in West London has a major road nearby, generating high concentrations of nitrogen oxides and ozone. The original large gateways in the ground floor link-room have been glazed with Perspex. Measurements of the ventilation rates of the building showed over 10% of the overall ventilation occurred through this small part of the building, bringing in high pollutant gas concentrations. The concentrations of sulphur dioxide, nitrogen dioxide, nitric and nitrous acid and ozone were measured as part of the Microclimate Indoor Monitoring for Cultural Heritage Preservation (MIMIC) project. One month's results are shown in Fig. 7. As can be seen, this part of the building provides very little protection, with indoor/outdoor ratios of all pollutants exceeding 66%. The room values for sulphur dioxide, nitrogen dioxide and ozone all generally exceeded those recommended for the display of graphic material. Recommendations do not presently exist for nitrous and nitric acid, although much of the damage previously attributed to nitrogen dioxide is now thought to have been caused by nitric acid [11]. The protective effects of the print frames in this room were investigated.

General results have been published previously [12], however, air-exchange rates of these frames were not measured due to the interventive nature of the procedure developed in that work. A new non-invasive method, based on oxygen concentration measurement, has been developed to overcome this, and details are included in Appendix 2. The three frames measured had air exchange rates of 1.23, 0.98 and 0.77 day^{-1}.

Diffusion tube based measurements inside such small volumes as print frame rebates are subject to much uncertainty, hence deposition based measurements were used to assess the frame's protective effect. Details are given in Appendix 2. All three frames tested showed very significant reductions in deposition rates, compared with the room values, with over 90% reduction in sulphate and 98% reduction in nitrate, see Fig. 8. The reductions followed the air exchange rates, with greater reductions occurring for lower air exchange rates, as would be expected with frames of similar size, constructed with the same materials.

The tight glazing of prints allows their sustainable display in historic properties in polluted areas. This, in turn, allows an intellectual access to the subject matter of the print in its original context.

MICROCLIMATE FRAMES FOR PANEL PAINTINGS

Panel paintings are often environmentally vulnerable. Well sealed, glazed frames, called microclimate frames, have been used at English Heritage for over 15 years, to allow presentation of such paintings in the non-ideal environments found in historic houses and castles. The *c.*1580 oil on panel painting of William the Conqueror (unknown artist) was incorporated into the new presentation at Battle Abbey Gatehouse in 2006. The gatehouse operates with two open doors, generating a highly ventilated and highly fluctuating internal environment. Daily RH fluctuations of 20% are often experienced and would present a very serious risk to the panel painting. A microclimate frame was constructed by glazing the front of the frame and building up the back to allow incorporation of a backboard. Construction details are given in Appendix 3. Although all materials had undergone, and passed, accelerated corrosion tests for metals [13], the effect of the concentration of gases inside such frames is unclear and is now subject to an EU sixth framework research project [14]. An 'SR002' datalogger was incorporated inside the frame, and its measurements have shown that the daily RH fluctuations are attenuated to below 1.5% and the RH in the frame has held steady between 50 and 65% over almost two years. The frame limits the moisture exchange between the panel and the room environment, hence significantly reducing changes in moisture content of the panel. In that time over 300000 visitors have experienced the image of William at the site of the battle that made him King.

CONCLUSIONS

Careful design and testing of enclosures can ensure they will provide suitable environments for even the most sensitive artefacts, in the most demanding environments. While conditioning systems have improved measurably over the past decade, they can only provide close control if the enclosures are sufficiently sealed. Even with extensive testing, unexpected factors can impact on the environment achieved, and development often needs to continue well beyond an exhibition's opening. A range of different solutions has been developed to answer the differing needs of presentation projects in historic properties. A balanced solution must consider long-term sustainability in terms of several resource issues. This work has allowed the presentation of a significant amount of material in its original context, even though the environments are extremely poor. It has facilitated access to these collections for large numbers of visitors, who would otherwise be unable to benefit from them. This has furthered English Heritage's responsibility of maintaining national collections for the public benefit.

APPENDIX 1: LOW RH SHOWCASE DESIGN

Thomson introduced the concept of hygrometric half-life in the 1970s [15]. Simple modelling of the internal RH from the measured room RH indicated a hygrometric half-life of 187 days would be required to keep the RH below 30% for six months. Assuming a silica gel loading of $10 kg.m^{-3}$ and using the equation developed by Thomson, this means an air exchange rate (AER) of less than $0.4 day^{-1}$ would be required. This was achieved using the following design features:

A lower back-hinged glass desktop case design was selected to lower AER. This has a single level seal, reducing air infiltration from the stack effect engendered by two vertically-separated horizontal cracks [16]. The glass lid had an internal metal flange around its lower edge. This mated to a flanged metal profile, such that the compression seal was compressed by the weight of the glass lid. Any air movement through that seal went through a 1 cm deep narrow horizontal gap between the two metal fittings.

The silica gel tray was placed directly underneath the display volume to reduce the vertical separation between the seals in its separate door and the glass seals. The heat gain inside the showcase is kept low by excluding internal lighting, and careful positioning to reduce heating from either windows or other display lighting.

APPENDIX 2: PRINT FRAME METHODS

A Ruthenium-based sensor (SensiSpot) is placed inside the frame rebate. Illuminating this with a Gas Sensor Solutions GSS450 Oxygen Analyser allows a measurement through the glass of the oxygen concentration by fluorescence quenching. The frame is enclosed in a sealed 'Escal' (oxygen barrier film) bag (with its own SensiSpot) with 'Ageless RP' sachets to remove the oxygen. Measurements of the oxygen concentration inside the bag are taken, and when the bag concentration drops below 0.1%, inside the frame rebate. When the frame oxygen concentration reaches 0.1%, the Escal bag is opened and the oxygen ingress into the frame measured to produce a second measurement of the air exchange rate.

Whatman's number 1 filter paper pieces were placed inside the frame rebates and exposed in the room atmosphere for 12 months. They were then removed, extracted with 18.2 MΩ water, and the extracts analysed with ion chromatography (Dionex DX600, AS14A column, 18 mmol sodium carbonate, 10 mmol sodium bicarbonate eluent). The concentrations of sulphate and nitrate were used to calculate the sulphate and nitrate deposition onto the filter paper pieces.

APPENDIX 3: MICROCLIMATE FRAME SPECIFICATION

A build-up is produced on the back of the original frame in the same wood species using traditional joinery techniques. This gives a depth to allow safe mounting of the panel with an additional 1 cm to incorporate buffering material and monitoring.

The inside of the wooden build-up is sealed with aluminium laminate (Moistop 622) adhered with 'Silastic 7443' silicone sealant. Preconditioned 'Artsorb' sheet with a surface area covering equal to the back of the panel is incorporated behind a brass mesh. Fears that incorporation of such hygroscopic material into frames with panel paintings can have adverse effects with temperature changes have recently been shown to be unfounded [17]. An SR002 logger is also incorporated, fixed to the grid, measuring air temperature and RH and surface temperature of the interior of the backboard. Since several of the microclimate frames are mounted onto potentially cold exterior walls, the potential for condensation and RH modification can be assessed from surface temperature measurements [18]. An extension lead is run from the logger's download port to a hole drilled through the newly built-up frame (sealed with Silastic 7443), allowing the logger to be downloaded without accessing the frame. The logger has a battery life guaranteed for 10 years. The backboard is formed from resin-tempered hardboard with the inside surface and edges sealed as the interior. The backboard is screwed into the build-up and onto a compression seal, and then self-adhesive aluminium tape (3M 425) is run around the four edges to ensure further sealing. A rebate is incorporated into the built-up frame to accommodate the backboard. The UV-absorbing, laminated, low reflective glazing is sealed onto the rebate with Silastic 7443. This process reliably produces a microclimate frame with an air exchange rate below $0.1 day^{-1}$. It is important to undertake tracer gas-air exchange rate tests on such frames with the frame in a vertical position, as this can have a dramatic effect on the air exchange rate measured.

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MATERIALS AND SUPPLIERS

Low RH showcase design EH1: Click Netherfield Ltd, 1A Goodsons Mews, Wellington Street, Thame, Oxfordshire OX9 3BX, UK. www.clicknetherfield.com

MG50 dehumidifier: Munters Ltd, Blackstone Road, Huntingdon, Cambridgeshire PE29 6EE, UK. www.munters.co.uk

SR002 and SR007 dataloggers: Just Data Loggers, 4 The Homestead, Longfurlong Lane, Gotherington, Gloucestershire GL52 9HA, UK. www.justdataloggers.com

Miniclima EB08 and EB09: Long Life for Art, Christoph Waller, Hauptstr. 47, D-79356 Eichstetten, Germany. www.cwaller.de/

Meaco radio transmitters: Meaco (UK) Ltd, Unit 4, 1 Cobbet Park, Moorfield Road, Slyfield Industrial Estate, Guildford, Surrey GU1 1RU, UK. www.meaco.com

Oxygen meter: Gas Sensor Solutions, The Invent Centre, Gladnevin, Dublin 9, Ireland. www.gss.ie

Moistop 622, Silicone Silastic 7443, self-adhesive aluminium tape M 425: Conservation By Design, Timecare Works, 5 Singer Way, Woburn Road Industrial Estate, Kempston, Bedford MK42 7AW, UK. www.conservation-by-design.co.uk

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