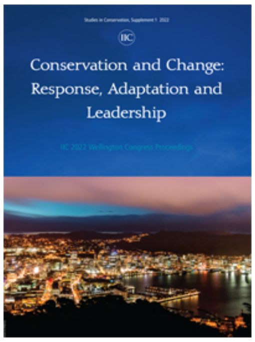

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ORIGINAL RESEARCH OR TREATMENT PAPER

Better Use of Showcases for Preservation and Sustainability

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ABSTRACT
Understanding an object's exact sensitivity towards its environment is critical for sustainability. This, and the building's performance, determine the amount of conditioning required in the showcase. Audit results have been combined with a critical literature survey to inform a research programme to generate such information. Methods to determine air exchange rate reliably have allowed the development of simple spreadsheets to predict showcase performance from the room's environment. Real data from 500 showcases have been used to test the predictions. Predictions were made for present and future carbon footprints. The approach has reduced English Heritage's carbon footprint significantly for this aspect of preventive conservation.

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KEYWORDS
Object response; showcases; sustainability

Introduction

Understanding artefacts' exact environmental requirements is essential to sustainability. Some objects are stable within some building environments with no, very little, or relatively low-energy environmental control, such as conservation heating or de-humidification (Thickett 2020a). Almost all objects in the UK environment have spent most of their existence subjected to low temperatures and higher relative humidity (RH) values. Continuous winter heating only became common in the nineteenth century and air conditioning (allowing tighter RH ranges and summer temperature control) was introduced into some museums in the 1930s. For less stable materials, an exact knowledge of environmental risk allows much better decisions to be made. For example, significant laboratory research and epidemiology has generated risk curves for terrestrial archaeological iron, shown in Figure 1 (Thickett 2012). Prior to this, the literature indicated several RH thresholds for archaeological iron, between 11 and 54%, and the impact of the common showcase pollutant acetic acid was unclear (Thickett 2012). This made managing environments for this material extremely difficult but understanding the exact response has allowed much better management. By balancing retention of archaeological value against available conservation resources, taking curatorial views on loss into consideration, a series of agreed RH values was determined. Within English Heritage, objects are stored at below 16% RH (in inert boxes) and the silica gel used to achieve these conditions is replaced when or before the RH reaches 16%. There are some instances in which iron will react at lower RHs, but the resources to change the silica gel are limited and a target of <16% reduces the risk to a very low level for the majority of objects. While such a threshold is technically feasible in showcases, it would be very expensive to maintain. English Heritage manages 142 showcases containing archaeological iron across 42 sites throughout England, from six main stores with silica gel ovens. This dispersed nature means there is a significant carbon footprint in controlling these showcases with dry silica gel (Thickett 2019). As can be seen in Figure 1, acetic acid has a strong effect on the deterioration rate at a given RH. As a result of an extensive refurbishment programme only four wooden showcases (generating acetic acid) are now used for archaeological iron.

To generate similar information for other materials important to English Heritage's collections, an extensive literature survey was undertaken to identify critical knowledge gaps. An operational approach was taken. If all environmental data (temperature, RH, light, ultraviolet (UV) radiation, pollutant gas concentrations and particulate deposition rates) were available at an object's exact location, could a reasonable risk estimate be made from the present state of knowledge? The impact of light and UV is generally well researched and risk assessment was found to be sufficient in most instances. For the other factors, much of the relevant research is in grey literature (conference proceedings and internal reports) some of which is still unindexed, despite great efforts by the BCIN and AATA online databases. Combined damage and risk audits on English Heritage's collections were completed in 2011 and 2021 (Xavier-Rowe and Fry 2011). The audit scores (combined from observed recent damage and risk assessment) are shown in Table 1.

Archaeological iron was determined to be the material responsible for most instances of objects

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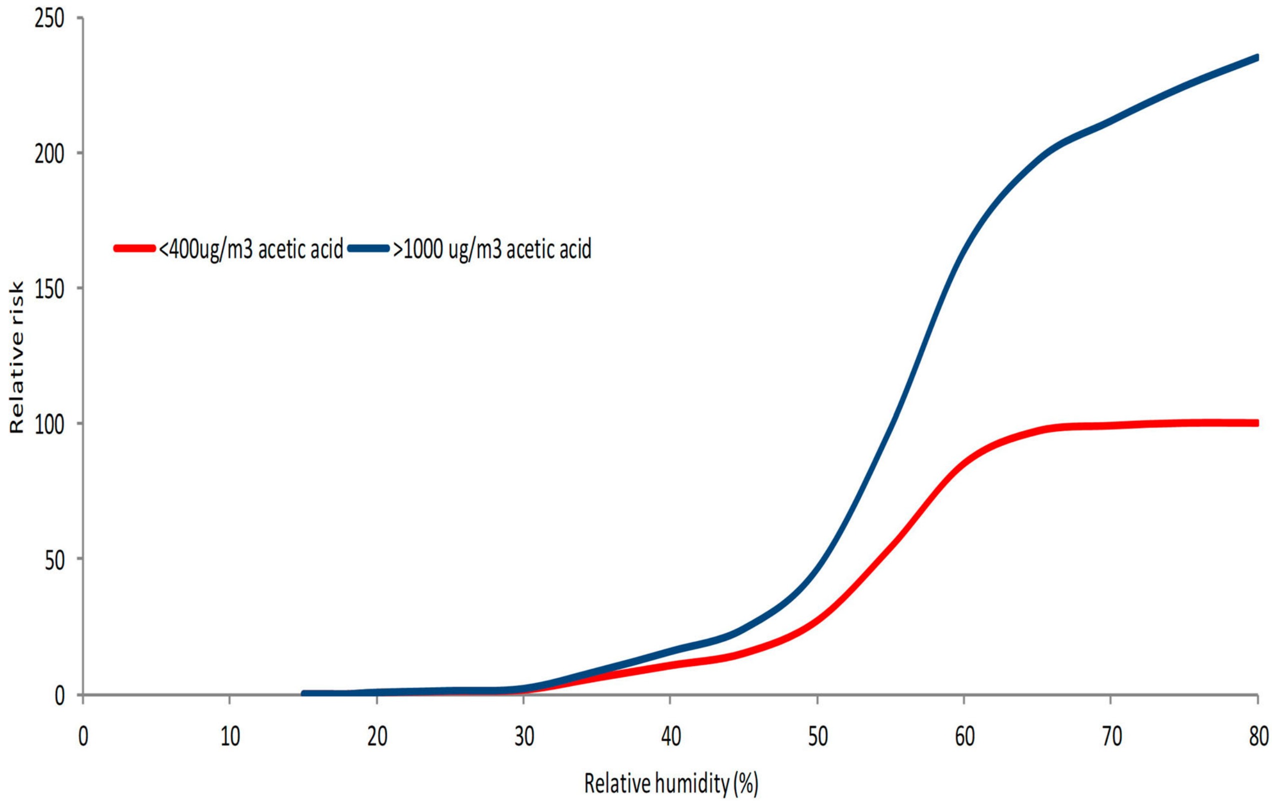

Figure 1. Relative risk to archaeological iron at different RH values and acetic acid concentrations.

Table 1. State of knowledge for the five most damaged materials in English heritage collections at completion of first and second national collections audits. Space limitations prevent a full listing of references.

	2011					2020					References
	RH in ideal range, no risk	Risk exceeding that range	Pollutants	Pollutants + RH	Particulates	RH in ideal range, no risk	Risk exceeding that range	Pollutants	Pollutants + RH	Particulates	
1 Ferrous metals (archaeological iron)	Some, but levels missing	Not enough knowledge	Not enough knowledge	Not enough knowledge	Not enough knowledge	enough	enough	enough	enough	enough	Thickett (2012); Thickett and Lankester (2012)
2 Wood	Some, but levels missing	Not enough knowledge	No impact	No impact	enough	Some, but levels missing	Some, but levels missing	No impact	No impact	enough	Thickett and Lankester (2012); Heri-e (2022)
3 Paint (canvas painting)	Some, but levels missing	Not enough knowledge	Some, but levels missing	Some, but levels missing	enough	enough	enough	enough	enough	enough	Mecklenburg (2007)
4 Non-ferrous metals (archaeological copper alloy)	Some, but levels missing	Not enough knowledge	Some, but levels missing	Not enough knowledge	Not enough knowledge	enough	enough	Some, but levels missing	Some, but levels missing	enough	Thickett (2016); Thickett and Lankester (2012)
5 Paper	Some, but levels missing	Not enough knowledge	Very significant disagreement in literature	Very significant disagreement in literature	Not enough knowledge	enough	Some, but levels missing	Very significant disagreement in literature	Very significant disagreement in literature	enough	Menart et al. (2014); Tétreault et al. (2019); Thickett and Lankester (2012)

Not enough knowledge | Some, but levels missing
enough | No impact
Very significant disagreement in literature

Table 2. Research areas from 2008 to 2021.

Research area	Related to materials (numbering from Table 1)	Type of project[a] Ongoing	Completed	Number of publications[b]
RH fluctuations	1, 2, 3, 4, 5	1 internal, 1 (climate), PhD	1 internal, 1 (climate)	8
Mould growth	2, 3, 5		1 internal, PhD (mould)	2
Treatment for outdoor objects		2 internal, PhD		2
Preventing damage to archaeological materials	1, 4	2 (metals), PhD, 3 Internal	1 (metals), fellowship	12
Storage methods	1, 2, 3, 4, 5	2 internal	2 internal	3
Appropriate enclosures	1, 2, 3, 4, 5	2 Internal		8
Non-destructive testing	1, 2, 3, 4	1 Internal	2 Internal	4
Testing and developing damage functions	1, 2, 4	1 Internal	2 Internal	5

[a]Almost all (22/27) projects are collaborative. Copyright prevents posting some paper PDFs and posting more recent papers was delayed by the pandemic.
[b]Most publications are available through https://www.english-heritage.org.uk/learn/conservation/collections-advice-and-guidance/ (accessed 10 April 2022).

with recent damage, initiating the research described above. The environmental response of organic objects is more complex than that of archaeological iron as mechanical damage (including fatigue and creep), chemical degradation and mould activity all need to be considered.

Initial results from part way through the 2011 audit were combined with the critical literature survey to develop a collaborative, focused research strategy (Table 2). This research aims to provide the required information on object response, management and environmental control, when these are not available from previous research. The research areas cut across several materials deliberately and the links to Table 1 are shown in the second column.

A collection's response to its environment determines the cost of maintaining an appropriate environment. Within the UK, there are generally two weeks during which the temperature is at its highest and a similar period with the lowest winter temperatures. In many buildings the highest indoor RHs coincide with the highest temperature period. The climates generated naturally inside buildings in many countries also show short seasonal peaks, which generate much higher air conditioning loads than the rest of the year. Designing systems to control these short-term seasonal peaks in climate or pollution significantly increases both their initial cost and maintenance.

Showcases

Even quite poor showcases mitigate many short-term RH fluctuations effectively. Showcases provide opportunities to control the environment, particularly RH and pollution, for a much smaller volume of air and can significantly improve sustainability. The improvement is much greater than the ratio of room to showcase volume, as the air exchange rate (AER, the ratio of air that flows into or out of a space to its volume) is in the order of changes per hour for rooms, while even poor showcases have AERs in the range of changes per day. At Swiss Cottage Museum, Osborne House, UK switching from controlling the room with dehumidifiers to controlling the showcases reduced energy usage by 94% (Thickett 2019).

Understanding temperature response is important as showcases provide little buffering of room temperature changes and these can be exacerbated by external lighting or internal temperature sources. Understanding showcase performance, and being able to predict it, is critical if this approach is to be successful.

Accessible methods of air exchange rate and leakage testing have been developed (Calver et al. 2005; Thickett 2021), which have allowed verification of published methodologies to predict internal showcase environment from that in the room. A series of spreadsheets was developed based on the hygrometric half-life approximation by Thomson (1977) for RH and the Weschler equation for pollution. The results of a study that compared the spreadsheet calculations with real showcase measurements for 53 low-RH showcases controlled with dry silica gel have been reported (Thickett 2020b). Results from a further 59 showcases showed similar results. The performance of 42 dehumidifier-controlled showcases was assessed using a spreadsheet that estimated the amount of water vapour that would need to be removed every 30 min, RH and room mixing ratio (Thickett et al. 2007; Thickett 2020b). The internal (acetic and formic acids) and external (nitrogen dioxide, ozone, sulfur dioxide) pollution levels for 46 showcases have also been reported (Thickett 2020b, 2022). Silica gels show hysteresis in their isotherms, with absorption measurements diverging from those for desorption, which can complicate calculations at moderate RHs. Samples of a newly-purchased regular (low RH) silica gel and Prosorb were measured with a Surface Measurement Systems Advantage dynamic vapour sorption analyser (DVS). The measured isotherms at 20°C are shown in Figure 2.

Regular silica gel shows no hysteresis up to just below 30% RH and its performance can be very well approximated by a straight line. The slope of the line for Prosorb, labelled as M, determines the buffering capacity of the gel. Above 30% RH, the performance depends on the direction of change of RH, ascending RH (M_A) or descending RH (M_D) in Figure 2. If the RH

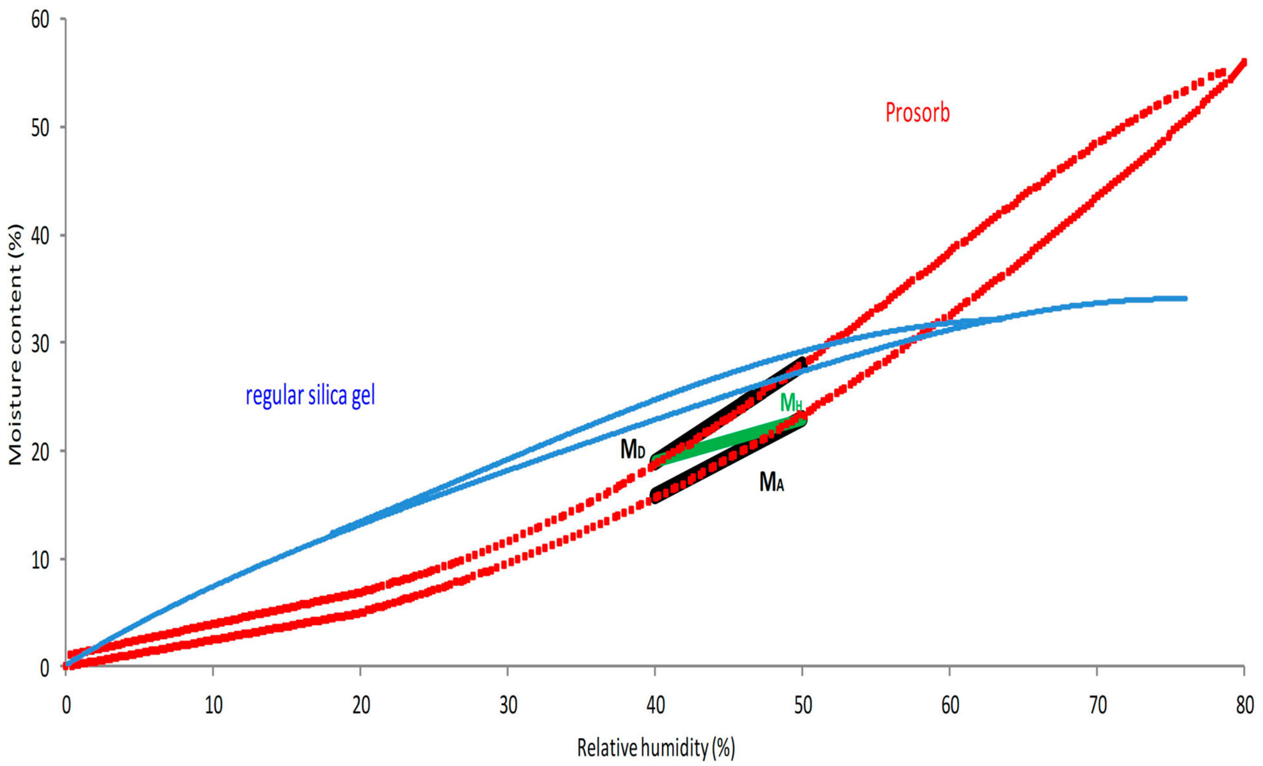

Figure 2. Isotherms for regular silica gel (blue trace) and Prosorb (red trace).

in the showcase fluctuates in the hysteresis region, the observed buffer capacity reduces to a value M_H, the hysteresis corrected buffer capacity (Weintraub 2002). In the hysteresis experiment shown in Figure 2 the DVS was programmed to run multiple cycles between 40 and 50% RH. The lines for Prosorb converge on the green M_H line after three cycles. Such experiments were undertaken at 5% RH intervals from 30 to 80%, generating a series of M_A, M_D and M_H values. These were used in the spreadsheet to approximate the internal showcase RH from the room RH, showcase AER and buffer loading. The properties of Artsorb, Artsorb sheet, Rhapid Gel, Zeolite 4A and Desi Pak bentonite clay were also measured.

An example of a calculation with this mid-RH spreadsheet is shown in Figure 3. As can be seen, the model approximates the measured showcase RH reasonably well, but deviates for some short-term rapid fluctuations that were not considered to pose significant risk of damage. These short-term periodic fluctuations were often caused by daily temperature changes. DVS measurements at a range of temperatures showed changes in the performance of the silica gel but, although these data could have been added to the model, the additional complexity was considered to outweigh the benefits.

The mid-RH spreadsheet was tested with data from 325 showcases. The showcase and room temperature and RH were measured with calibrated (UK National Measurement Accreditation Service traceable) Rotronic hygroclip probes with a stated RH accuracy of 0.8%. Showcase AERs were measured, the volume calculated and the necessary mass of Prosorb (in cassettes) determined. The required accuracy of the estimation method was set to 3%, as mandated by BS EN 16242 for RH measurement accuracy for cultural heritage (BSI 2012). The majority of cultural heritage institutions in the UK use monitoring with this accuracy.

Table 3 shows the number of showcases against the percentage of time that the estimated RH was within 3 or 4% of the measured RH in the showcase. The results are shown in two groups:

- those showcases that were considered hygrometrically inert, with very little RH buffer present beyond the Prosorb;
- those that had other buffers present (MDF, interpretation panels or hygroscopic objects) at a level greater than 1 $kg.m^{-3}$.

The estimates for the inert showcases were close to the measured values, with only one out of 122 agreeing for less than 90% of the time. Those data points that exceeded this divergence were close to the 3% figure and very few exceeded 4%, which is also shown in Table 3. Unsurprisingly, the showcases with other buffers present did not perform as well. Work will continue to improve predictions for such showcases, using mass balances based on isotherms measured at several temperatures.

The calculations can be used with measured or predicted room data to determine the AER required for a

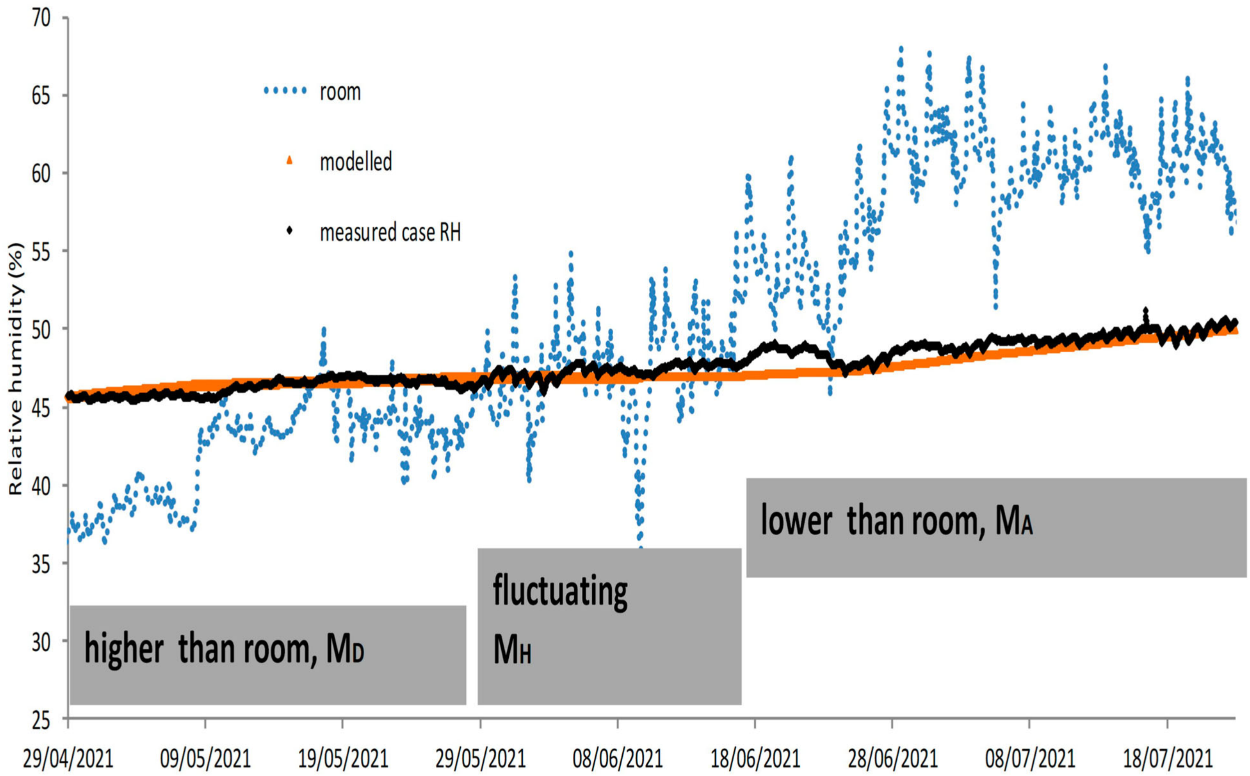

Figure 3. Modelled and measured RH data for a showcase controlled to ambient RH.

particular showcase, with certain contents, in a particular situation. Combined with showcase AER testing and improvement if required, this guarantees environmental performance when showcases are installed or refitted. Guaranteeing performance is critical in the design process. Suitable contractual requirements need to be in place to ensure the AER performance of new showcases is met. Several return trips by manufacturers can be required to ensure a new showcase performs.

Table 3. Performance of mid-RH modelling, showing number of showcases with percentage time in various RH bands/situations.

Percentage of time within RH range of measured value	Number of showcases in situation, RH range		
	Inert, 3%	Inert, 4%	Buffer, 3%
83			1
84			4
85			2
86			6
87			15
88	1		17
89	0		13
90	2		8
91	4		3
92	10		1
93	8		6
94	9		1
95	13	1	3
96	18		1
97	13	2	
98	13	13	
99	14	27	
100	17	80	

Sustainability

Combining research (both laboratory-based and epidemiological) for environmental requirements with the prediction of showcase internal environments allows showcases to be tailored to their environmental and performance requirements. The predictions from the spreadsheets can be combined with life cycle greenhouse gas emission (GGE) information to calculate carbon footprints. For showcases (and other equipment), only manufacturers can generate primary information from cradle to site, but no such information has been published to date. Methods are available, however, that assess secondary information, such as the mass of component materials and national average figures for their production (BSI 2011; Swedish Life Cycle Center 2022). Many showcase manufacturers provide 3D files, from which material volumes and masses can be calculated. When more accurate manufacturer-derived carbon footprints become available, they can readily be inserted into the calculations. For a showcase controlled with silica gel, the showcase embedded carbon is combined with: the embedded carbon to produce the silica gel; the carbon required to dry the silica gel (14.5 kW hours for 9 kg of regular silica gel, equivalent to 3 kg GGE – i.e. the mass carbon dioxide released) or to condition it (6 kW hours for 8 kg Prosorb conditioned to 20°C and 38% RH, equivalent to 2 kg GGE); and the carbon used when the silica gel is replaced. English Heritage staff produce GGEs when they travel to service the sites

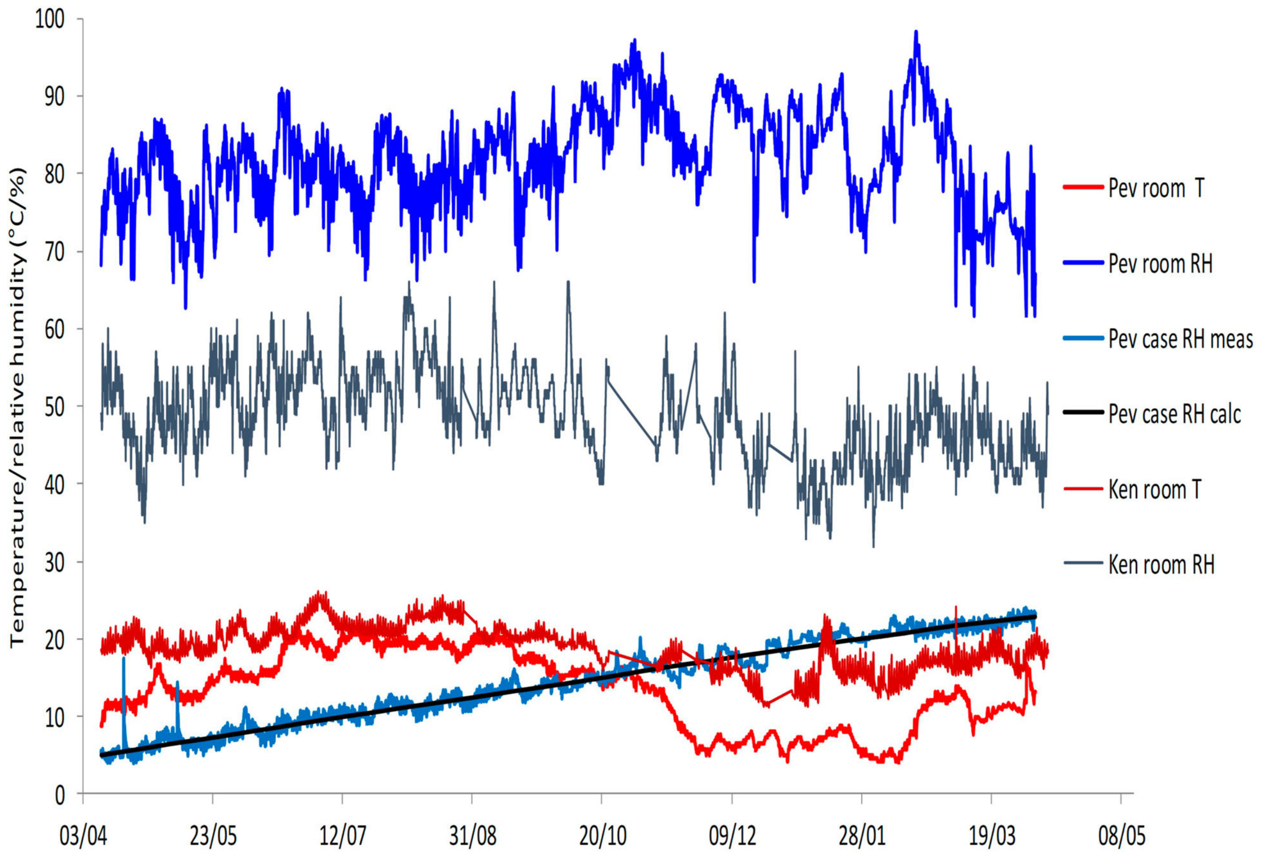

Figure 4. Conditions in Pevensey Castle (Pev), in Kenwood House (Ken) and inside a showcase in Pevensey Castle.

with silica gel-controlled showcases. There has not been a peer reviewed assessment of silica gel embedded carbon to ISO 14040 (ISO 2006) published to date. The material appears on the *Sustainability Tools In Cultural Heritage* website, as 'coming soon'.[1] The embedded carbon for ovens to recondition silica gel is not considered a significant contribution, as their very long operating life spreads this over hundreds of reconditioning cycles. Similarly, the GGE from the design and installation processes, travel and overnight stays is considered relatively small compared to that generated by maintaining the environments, as showcase lifetime is generally over 20 years. This would certainly be much more important in an analysis for temporary exhibitions if showcases were continually changed.

Machines can also be used to control showcase RH. Calculating their carbon footprint requires both the embedded carbon for the equipment and the carbon equivalent for the electricity its operation consumes. Several common types of conditioning equipment have been disassembled and the component materials analysed (with XRF for metals and FTIR for plastics) to determine the mass of each material present. With suitable manufacturer information on the capacity of the equipment at different temperatures, the room temperature and RH, and the target showcase RH, the demand for energy can be predicted.

Figure 4 shows the temperature and RH for rooms in Pevensey Castle and Kenwood House. Pevensey Castle is much damper and on the average cooler as the building has a much higher thermal mass and is not heated in the winter. A $1000 \times 600 \times 300$ mm glass and steel desktop type case has embedded carbon of just over 87 kg GGE. Calculations with the spreadsheets indicate 4 kg of dry (5%) silica gel will keep the RH below 30% in Pevensey for 12 months in a showcase with an AER of 0.4 per day. All sites with collections are visited by conservation staff at least once a year, so significantly longer lifetimes are not particularly beneficial. Additional silica gel is generally added to increase the lifetime to 18 months, to allow for scheduling issues; this was particularly useful during the recent pandemic. Pevensey Castle is 250 km from a store with a silica gel oven. In Kenwood, 2 kg of silica gel is needed to maintain the RH below 30% for 12 months and it is 65 km from the nearest store. Considering a 20-year period and World Harmonised Light Vehicle Test Procedure data for the most common hire car used generates the data for one and four showcases shown in Table 4.

If a mechanical method is used to maintain the RH below 30%, the embedded carbon equivalent to 93 kg GGE for the Munters MG50 dehumidifier needs to be considered. Figure 5 shows the demand calculation and the capacity of this dehumidifier. Running the demand spreadsheet and linking the results to the dehumidifier's reported performance indicates an electricity usage of 14 kW hours per annum at

Table 4. Carbon footprints for silica gel and dehumidifier control of one or four showcases at two sites. For each situation the lowest value has a grey background.

Silica gel controlled

	Number of showcases	Total mass of glass	Total mass of steel	Total mass of MDF (plinths only)	Showcase embedded carbon (kg)	Mass of dry silica gel (kg)	Distance (miles)	Visits per year	Person days per year	Carbon footprint (kg CO_2 over 20 years)
Pevensey Castle	1	50	20	15	349	4	160	1	1	707
Kenwood House	1	50	20	15	349	2	41	1	1	441
Pevensey Castle	4	50	20	15	1396	16	160	1	1	1754
Kenwood House	4	50	20	15	1396	8	41	1	1	1487

Dehumidifier controlled

						Number of dehumidifiers	Dehumidifier embedded carbon (kg)	Filter embedded carbon	Maintenance visits	Energy usage (kg CO_2 equivalent)	Carbon footprint (kg CO_2 over 20 years)
Pevensey Castle	1	50	20	15	349	1	32	4	61	98	545
Kenwood House	1	50	20	15	349	1	32	4	34	67	487
Pevensey Castle	4	50	20	15	1396	1	32	4	61	98	1592
Kenwood House	4	50	20	15	1396	1	32	4	34	67	1534

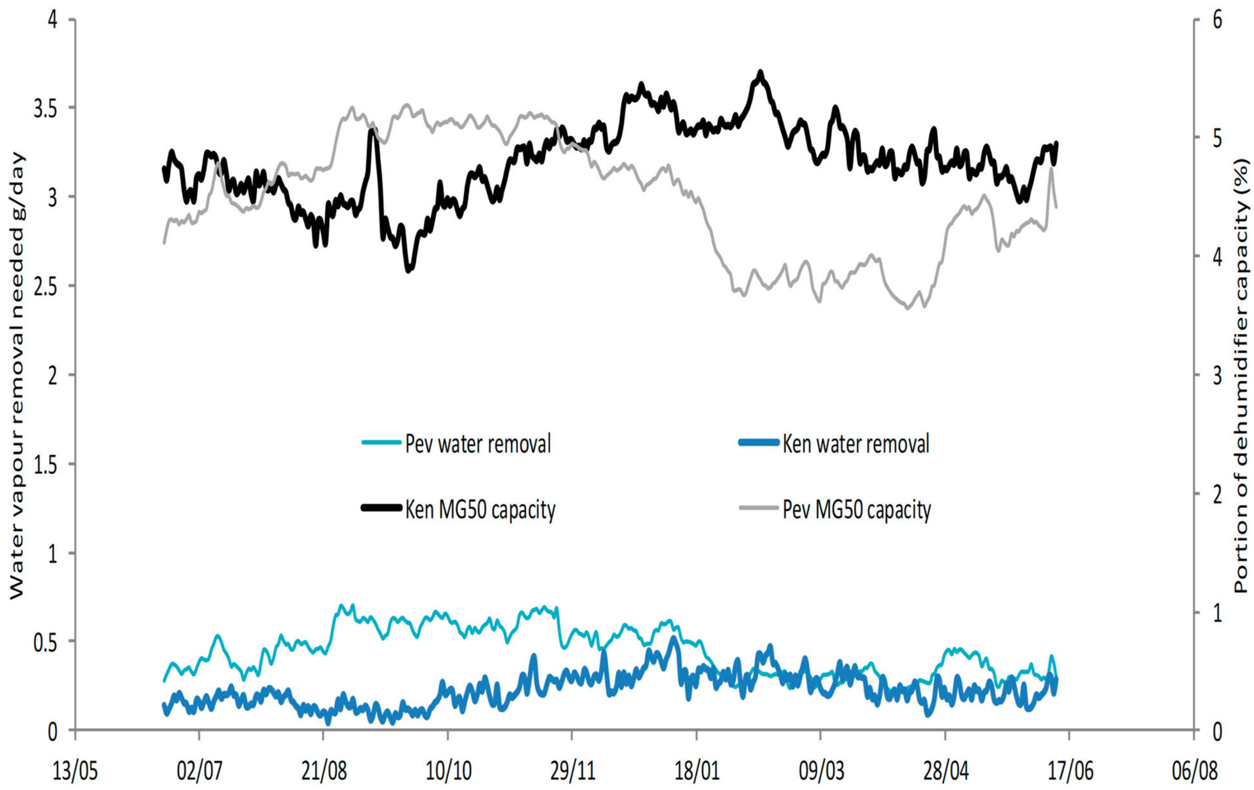

Figure 5. Dehumidification requirement at Pevensey Castle (Pev) and Kenwood House (Ken), and the dehumidification capacity of the Munters MG50.

Pevensey and 8 kW hours per annum at Kenwood. As Figure 5 shows, there is sufficient capacity for all four showcases to be controlled from a single dehumidifier provided trunking can be run between them. The calculations are included in Table 4.

This example is for the low RH environments required for archaeological iron. In some instances, the passive approach has a lower carbon footprint (Kenwood), but in others (Pevensey) using dehumidifiers results in lower emissions. Modelling silica gel-controlled mid-RH showcases requires extra information as hysteresis alters the performance of the silica gel in these RH ranges (Weintraub 2002). This has been measured for common silica gels and new spreadsheets developed incorporating the hysteresis affects (Thickett 2021). The approach described above for mechanical control can be adjusted to the mid-RH range by adding a lower RH limit.

Assessments have been made for 383 of the 437 showcases used across English Heritage's estate. The remaining showcases are over 30 years old and it is difficult to assess their embedded carbon accurately without complete disassembly. The measured total carbon footprint over a 20-year lifetime is 89,000 kg GGE. This compares with an estimate made 16 years ago of 204,000 kg GGE. This is a reduction of just over 55%, despite a small increase in showcase numbers over that period. The reduction is slightly greater than that already reported for the low RH showcases alone (Thickett 2019). The longer period between changing silica gel also saved over 210 person days per year, showing that this approach can lead to significant cost and carbon footprint savings.

Life cycle assessment includes disposal after end of useful life. An English Heritage database of showcases allows reuse for smaller cases and facilitates changes to displays, while research into refitting showcases has reduced the number being replaced (Thickett, Stanley, and Booth 2008). New displays over the past four years have incorporated over 40% of refitted existing showcases. Refitting is also important curatorially, as English Heritage has a number of historic showcases, which have significant heritage value in themselves.

Monitoring has shown clear signals of changes in internal climate, probably driven by external climate change. London experienced unprecedentedly high temperatures in 2018 but, fortunately, few cultural heritage materials are particularly temperature sensitive and damage was limited to very small losses from Limoges enamel plaques. Recent changes in RH are of more concern as, for the past three years, some London properties are showing low RH (30–35%) periods for several days in April and May. This had not been observed in the previous four decades and poses a significant challenge to the conservation heating systems used. At Osborne House, Isle of Wright, both the Swiss Cottage and Swiss Cottage Museum had much damper winters than previously experienced (Figure 6). Averaging the difference in readings for the same day and time across years gave values of 4.3(2020–2018) and 3.5 (2019–2018), compared to less than 1.3 for any other pair of years. Conservation heating and additional

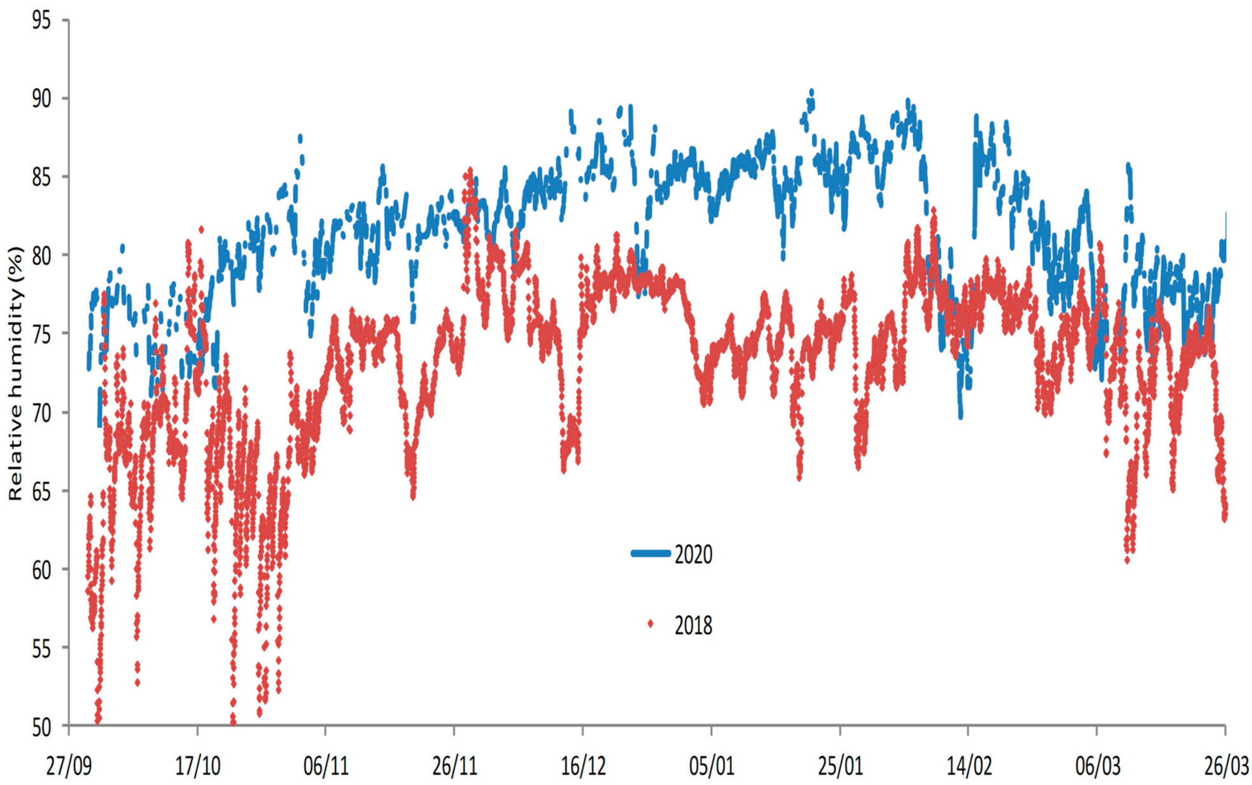

Figure 6. Winter RH conditions at Swiss Cottage Museum, Osborne House in 2018 (red trace) and 2020 (blue trace).

dehumidifiers are now used to mitigate these more aggressive environments.

The approach adopted for showcases allows ready adaption and a good quantification of what will be required in the future. For example, research by Lankester (2013) generated internal temperature and RH values for a room in Kenwood House, London from future climate predictions. When these values were fed into the calculations described above, the number of days between silica gel changes required to keep a showcase containing 2 kg silica gel below 30% was 330 in 2035 and 320 in 2085. Although little change is predicted in this example, in other instances such predictions can be used to balance several potential options. The predicted lifespan might be used to determine whether passive conditioning with silica gel would be feasible within an institution's resources, whether those resources need to increase, or whether replacement with a new lower AER showcase would be more sensible than changing to a dehumidifier.

The research has enabled collections to be displayed in many sites that have very taxing environments, e.g. that at Pevensey Castle (Figure 3). In this environment, the showcase described keeps the RH below 25% for 12 months with 4 kg of dry silica gel. This has significantly reduced maintenance costs and driven local development. Visitor numbers are recorded, and most new displays increase these by at least 30%, with visitor surveys often indicating that the projects have a positive impact on the local economy. The surveys also reveal that the presence of 'real' historical objects on site is a significant driving factor for visits. The surveys clearly demonstrate that nearly all these trips would have been made to other attractions had the English Heritage site not been chosen, so were not increasing travel.

Dissemination

The Excel spreadsheet programme was selected as a platform for the calculations due to its very wide availability. It has some drawbacks, especially in how it deals with date formats from different countries and its limited computational facilities. The spreadsheets were designed for general use and extensive instructions also made available. Part of the work was developed in the EU project *Measurement, Effect Assessment and Mitigation of Pollutant Impact on Movable Cultural Assets* (MEMORI) which ran 2011–2014.[2] Its target audience included all decision-makers in cultural heritage institutions, including those without professional conservators or curators. Hence a large amount of background information and explanation was included in the 600-page decision support model produced. This, along with the spreadsheets, instructions and other information, presently resides on both the Norwegian Institute for Air Research (NILU) and English Heritages websites. It is planned to add it to the Heri-e website in the near future.[3] The funding model for such large interdisciplinary European Framework research projects does not include long-term website funding and several important project websites and tools are no longer accessible. It is hoped that dispersed availability will circumvent the loss of access to any single website in future.

A series of online tools has been used to distribute the approach across the field. These are regularly used by several training courses. The approach has been reinforced to mid-career professionals with a series of papers and hands-on workshops. With the pandemic in 2020, the material moved to online presentation. A university training course and full day workshop at the American Institute for Conservation (AIC) meeting were scheduled and the online nature of the material and extensive background information made transfer to an online format relatively simple. Both workshops transformed into three sessions of three hours spread over several weeks. This improved delivery, as the material is very dense for a one-day course and the intervening periods allowed participants to read the background information and better contextualise their own issues. The move from demonstrations, limited by the number of people who could gather around a showcase, to videos increased the number of participants. Sixteen workshops were held that introduced over 500 conservation professionals from a broad geographical spread to the methods. The methods and results have helped to inform the drafting of a new European standard on technical aspects of showcases and to encourage changes in conservation practice, allowing end users to tailor the results to their environments and situations.

Notes

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2. MEMORI. Accessed 10 April 2022. https://memori.nilu.no/.
3. Heri-e. 2022. Accessed 10 April 2022. https://herie.pl.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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