2009

Environmental Management Performance Standards

Guidelines for historic buildings

ENGLISH HERITAGE

Contents

Introduction to Environmental Performance Standards

These Environmental Performance Standards are essential reading for anyone responsible for managing collections within historic buildings.

These Standards have been developed from six high-level guiding principles on environmental management and are underpinned by real-world advice based on the wealth of knowledge and experience of English Heritage staff managing some of the most renowned historic properties in England.

These guiding principles are:

1 Involve all relevant disciplines in environmental decision-making – when in doubt, it is better to include rather than to exclude others' contributions. Until the recent past, it was considered the responsibility of the conservator to manage the environment around a collection. Now it is widely accepted that buildings and structures influence the indoor environment, and that in turn the external environment affects the condition and behaviour of buildings and structures. The interdependence of the work of conservators, curators, conservation scientists, architects, engineers and facilities managers is illustrated by case study 3: Secret Wartime Tunnels at Dover Castle, Kent, which demonstrates the multidisciplinary nature of decision making for environmental control.

2 Whatever standards you choose to use, think about their relevance and apply them to your circumstances – do not accept them in their entirety without question.

National standards (BS 5454) exist for archive documents on exhibition and in storage, and there are published specifications for environmental control in museums and galleries. These standards and specifications may not always be appropriate for un-adapted use in the historic environment. Case study 4, on the Royal Garrison Artillery Barracks at Dover Castle, Kent, illustrates environmental control for the storage of archaeological and historic material in a building not constructed for this purpose. Care must be taken to balance improvements in environmental conditions for collections with the impact these changes will have on the building.

3 Manage the environment as though the inside and the outside are equally important – collections already have one layer of protection – the building – but historic buildings must also be protected in their own right.

Purpose-built museum buildings are designed to protect collections as well as to provide for the comfort of visitors and staff. In contrast, a historic building itself may be the first and most important object, as illustrated in case study 1: Chapel of St. Leonard, Farleigh Hungerford Castle, Somerset. Here, preventive and passive measures were evaluated in order to understand better how to attenuate the effects of the environment on a historically sensitive building fabric.

4 Think about the climate, the weather and the changing seasons – work as much as possible with the environment rather than against it – it can be a benefit as well as a threat.

Historic buildings may be vulnerable because of their location, construction and condition; threats to a building's fabric are increased when the climate, weather and the seasons are ignored when major work is planned on such buildings. Case study 2 on Brodsworth Hall, South Yorkshire demonstrates the opportunities for sustainable environmental management provided by refurbishment projects.

5 Develop a positive attitude to reducing dependence on fossil fuels as sources of energy.

Traditionally historic buildings, judging by today's standards, made responsible use of fossil fuels, because of their scarcity and the hard work necessary to procure them at the time. Today, it is possible to build on this principle by developing display strategies that do not depend on high use of energy for environmental control. Case study 6 on Rangers House, Blackheath illustrates that the use of microclimates in display cases has proved itself to be a sustainable exhibition strategy, not only in museums but also for museum-type exhibitions in historic properties.

6 Remember that, while we are responsible for the historic environment, we are also stewards of the whole of our heritage, both natural and cultural.

Antoine de Saint Exupéry remarked: 'We have not inherited the earth from our parents, we have borrowed it from our children'. While we may exploit the benefits of the historic environment, case study 5 on Chiswick House, London demonstrates the kind of responsible and complex planning needed when hiring a historic property used for private events.

These principles distil the recommendations on environmental management contained in these guidelines. The guidelines expand upon these principles and illustrate their application in a number of case studies, which focus on important English Heritage assets – its historic collections. This focus on collections that are integral to the interiors and to the interpretation of historic properties go to the heart of the integrated management of the indoor environment.

This approach obliges us to think holistically and pragmatically about what it is necessary to do for collections conservation and to consider the extent to which environmental control as defined by museums and galleries is applicable to historic buildings. It is rarely desirable, although it is a useful starting point, to use the ranges of relative humidity (RH) and temperature control in museums. These are often defined as: RH between 50% and 60% and temperature between 19° and 24°C. However, even in museums, seasonal variations are accommodated in recognition of the technological difficulty, cost to the institution and risks to the environment of mechanical systems. Mechanical control is not an easy option and should not be the first choice for historic properties.

Instead, the range of environmental control for collections within historic buildings in the currently temperate climate of England should aim at an RH between 40% and 65% and a temperature no higher than 7° above external conditions. This can be very cold for human occupants standing or sitting for any length of time. We also need to be mindful of the impact of climate change on the historic environment that can affect how gutters, down pipes and buried drain pipes cope with the predicted increase in incidents of intense and prolonged rainfall.

Good maintenance is the key to good management. Historic buildings can become vulnerable to the weather owing to their locations, construction, types of use and lack of maintenance. Within the topography of a site, the ground immediately around a building should slope away in order to ensure that surface water during heavy rain runs away from, not towards, the building. Masonry or brick walls are vulnerable to bad repairs involving cement or cement mixtures, while timber in the structure is at risk from wetting or high humidity, which can lead to direct or indirect failures, such as pest infestation. At roof, ground and subterranean levels flat roofs, parapets, attics and cellars need protection from standing water, and progressive damp patches need to be investigated. Chimney stacks connect to flues and fireplaces where evidence of damp soot or fragments of flue lining may indicate a problem of damp penetration at a higher level. Engineered heating appliances such as boilers, pipes and water or oil-filled radiators must be regularly inspected for leaks and rainwater goods such as gutters and down pipes and ground level drainage systems such as manholes, grilles and drains must be regularly inspected and regularly maintained. This will avoid back-splashing on walls and penetrating damp into walls, ceilings and floors, which can damage interiors, promote mould growth and destabilise internal RH and temperature. The sills of doors and windows should be inspected for water stains, peeling paint, blackening wood and dirt on internal sills.

A building maintenance programme must therefore not only be planned, but it must also be executed in order to reduce the risk of water penetration, higher levels of indoor relative humidity and an increase in the incidence of mould growth. For these reasons, the Environmental Performance Standards in the following six case studies are specific to the conditions in each case, rather than prescriptive or absolute. They follow objectively based standards, tailored to individual historic properties, whose distinctiveness in each example is defined by the institutional aims and statements of significance and function of the property. This methodology, applied to each case study, demonstrates that it is possible to define the standards of environmental management required by different properties, and to design environmental solutions appropriate to their individual performance and use.

English Heritage is developing conservation management plans for many sites in its care. Each plan provides a useful framework for evidence-based decisions, including environmental management decisions, by placing the value and significance of the historic environment at the heart of the plan.

A conservation management plan explains to everyone involved in the stewardship of the historic environment: what issues matter, and to whom; and what is happening to the property and what needs to be done. These Environmental Performance Standards – the framework and the case studies – are intended as tools for effective conservation management within the context of a conservation management plan.

The Environmental Performance Standards framework comprises:

Title
Aim
Statement of significance

Project outline:

- mission
- function
- staffing

Performance requirements:

- site description
- presentation and interpretation
- conservation and collection care issues
- comfort of occupants
- display strategy
- storage
- project management
- solution concept
- control strategy
- maintaining the building

Achieving and maintaining an acceptable solution:

- ground drainage
- maintenance of the fabric
- re-roofing to improve environmental stability
- heating/cooling
- dehumidification
- natural or mechanical ventilation?
- zoning
- microclimates
- cleaning of objects affected by mould
- monitoring, including alarm-based monitoring

Lessons learned and future actions:

- integration of building, site and landscape
- understanding cause and effect of building alterations
- working with the building
- enhancing visitors' enjoyment
- mechanically assisted natural ventilation

Principal references

Cassar, M 1994 Environmental Management Guidelines for Museums and Galleries. London: Routledge

Chicora Foundation 1994 Managing the Museum Environment. Columbia, South Carolina: Chicora Foundation Inc

Journal of Architectural Conservation (the international journal for historic buildings, monuments and places; published in March, July and November). Shaftsbury: Donhead Publishing

Nationalmuseet 2007 Museum Microclimates: Conference on Preventive Conservation (Copenhagen 19–23 November). Copenhagen: The National Museum of Denmark, http://www.nationalmuseet.dk/sw30434.asp

The National Trust 2005 Manual of Housekeeping: the Care of Collections in Historic Houses Open to the Public. Oxford: Butterworth-Heinemann

Thomson, G 1994 The Museum Environment (2 edn). London: Butterworth-Heinemann

Organisations that provide advice:

English Heritage is a non-departmental public body of the United Kingdom Government (Department for Culture, Media and Sport) with a broad remit to manage the historic environment of England. For advice call: +44 (0)20 7973 3000.

Historic Scotland is an executive agency of the Scottish Government, charged with safeguarding the nation's historic environment and promoting its understanding and enjoyment on behalf of Scottish Ministers. For advice call The Enquiry Service, Technical Conservation Group: +44 (0) 131 668 8668.

CADW: Welsh Historic Monuments is the Welsh Assembly government's historic environment service. Its aim is to service the conservation and appreciation of the Welsh historic environment. The expertise of Cadw, including architects and surveyors, is made available through its publications. For advice call: +44 (0) 1443 336000.

Northern Ireland Environment Agency (NIEA) is the largest Agency within the Department of the Environment taking the lead in advising on, and in implementing, the Government's environmental policy and strategy in Northern Ireland. Its aim is to protect, conserve and promote the natural environment and built heritage for the benefit of present and future generations. For general inquiries on historic buildings call: +44 (0) 28 9054 3095.

Case study 1 Chapel of St Leonard, Farleigh Hungerford Castle, Somerset

Evaluating preventive and passive measures to moderate the effects of the environment on historically sensitive building fabric

Aim

To understand the inherent environmental performance of the building, the condition of the fabric and the impact of subsequent alterations in its use, as a means of determining strategies for improving the internal environment for the benefit of both the building and its contents. By breaking the cycle of reactive repair, to initiate a programme of informed building maintenance and management.

Statement of significance

The Chapel of St Leonard is nestled among the ruins of Farleigh Hungerford Castle, an extensive fortified building dating from the late 14th century. Originally the local parish church, the Hungerford family converted it into their private family chapel in the 1440s. Despite numerous periods of neglect and disrepair, and extensive alterations to the fabric, the chapel stands virtually intact and contains a series of important medieval wall paintings, numerous family tombs and a small collection of late Jacobean wooden furniture. The crypt contains arguably the finest collection of 16th- and 17th-century anthropomorphic lead coffins in England.

Project outline

To further English Heritage's policy, which emphasises the importance of maintenance, the site usefully illustrates the significance of preventive as opposed to corrective maintenance in mitigating deterioration factors, and in sustaining the best possible conditions within the chapel through passive means of environmental control.

Performance requirements

Site description: The chapel comprises two main spaces: a large single rectangular space incorporating the nave and chancel under an open-trussed, stone-tiled roof, and a smaller north chapel with lead roof over a vaulted crypt. Later additions include a small western porch (16th century) and a small wash building abutting the north-east corner (now incorporating public toilets on the ground floor, and the ticket office and shop above).

Encircled on its north and west by a modern perimeter wall, the chapel is partially embedded into the sloping crest of land, with the main nave some 1.2m below ground at the west end, while at the east end, the floor of the chancel is almost 2m above external ground level.

Presentation and interpretation: Before a solution concept and control strategy can be developed, activities that can affect the interpretation of the chapel need to be assessed, because sound environmental management must be based on quantitative or qualitative evidence and data. These datasets must inform the original objective or purpose of the display and interpretation of the chapel, and the development of performance standards. Useful datasets include:

- actual and planned number of visitors and events
- available surveys and environmental monitoring data
- opening hours and use patterns
- diagnostic environmental monitoring to assess the suitability of a space for the intended use

It should be noted that such evidence can be gathered through non-invasive and non-destructive methods, which should always take priority.

The objectives for the presentation of St Leonard Chapel could be described as follows:

- To communicate the complex and cumulative history of the chapel within the context of Farleigh Hungerford Castle and its grounds, highlighting its architectural and artistic beauty.
- To minimise additional technological interventions, such as lighting and climate control, while enhancing the visitor appreciation of the quality of the interior, fixtures and fittings.
- To undertake necessary repairs to the building fabric in a sympathetic way that can assist in controlling relative humidity and temperature.

Fig 1 Chapel of St Leonard.

- To utilise space within the adjacent Priest's House for site interpretation and visitor facilities, thereby avoiding excessive infrastructure and activity within the chapel, which might put the fabric at increased risk.

Conservation and care issues: In reality, the capacity for preservation of historic buildings is frequently compromised by previous restorations and injudicious use of added materials. Furthermore, the need to balance preservation of the fabric with the capacity of the building for visitor access is a relatively recent challenge. This means that any conservation intervention must consider that the building no longer functions as it was originally designed.

Solution concept: Typical of many medieval structures, the chapel was not designed with any deliberate means of environmental control, but rather has relied on the passive buffering of the structure. Equally common, the chapel has been subject to numerous physical alterations, not least the blocking of the nave windows, the loss of external render, and modern re-pointing with cementitious mortar.
The chapel interior retains sensitive historic wall paintings, which are integral to the fabric, so the nature of the building envelope and its limitations needed to be assessed before designing the right control strategy.

The introduction of fixed mechanical environmental control is neither feasible, nor desirable for this site. Previous interventions have been limited to the introduction of a few basic storage heaters, whose heat output compared to the air volume of the chapel does not have a significant impact on internal stability. There has never been any agreed operational regime for the heaters, but the custodian could have nominal control by switching them on and off. The development of an environmental control strategy can offer passive remediation, and in combination with targeted repairs and maintenance can assist in reducing the rates of deterioration to the chapel and its interior.

Control strategy: An environmental control strategy must be based on an in-depth understanding of the changes that have occurred to the building in the past. The following three measures summarise the process of developing a control strategy:

- Understanding the inherent features that promote environmental stability in a historic building: these are given, but they must be understood if they are to be used to their full potential.

Fig 2 East end of the chapel including wall painting of St George.

- Taking further action to enhance passive control: this involves capital expenditure. Works improved the capability of the building to resist the weather, such as enhancing the rainwater goods and improving the stability of internal conditions with a new, insulated, roof in 2001.
- Taking additional routine measures to maintain control: for which an additional expenditure will be required. This requires an effective building maintenance programme to sustain the condition of the chapel. However, at Farleigh Hungerford, where the maintenance budget for the chapel is part of the maintenance budget of a larger site, its needs have to be compared with other urgent issues, such as collapsing walls, which have health and safety consequences, and priorities decided.

English Heritage carried out a number of key technical studies to characterise the environment in and around the building before deciding on the control strategy appropriate to the chapel. These studies comprised:

- research on the physical history of the site and its buildings;
- a condition survey of both the building and key significant features;
- a survey of microbiological staining on the site;
- a survey of the different site levels for the efficacy of water drainage;
- a liquid moisture (as opposed to water vapour) survey;
- moisture profiling of the walls using drilled samples;
- and initiation of a monitoring programme.

They demonstrate the complexity of the environmental issues surrounding the chapel and that the whole building was intended to benefit from any adaptation to avoid condensation risks.

Achieving and maintaining an acceptable solution

Ground drainage: Where problems above ground (such as damp lower portions of walls)

Fig 3 Enclosure around Chapel of St Leonard, showing ground sloping towards the chapel.

are evident, drainage may need to be characterised in order to isolate any problem caused by underground conditions. In the case of St Leonard Chapel this should not have huge resource implications.

Maintenance in context: Maintenance of the chapel cannot be restricted to just the visible structure when the condition of the land around it and the underground drainage are so critical to its well-being. The chapel is situated in a hollow surrounded by a battlemented retaining wall. This creates a local context for the building. Vegetation and silting of the drains are critical issues for the chapel's maintenance. A regular programme of preventive maintenance is necessary to reduce water ingress into the walls. Gullies must be kept clean and free from vegetation if they are not to retain liquid moisture and cause damp penetration. This building has a gully along the west wall.

Maintenance of the fabric: As early as 1839, a trust was set up to maintain the chapel, and which may have been associated with one of the roof repairs in 1840. Nevertheless, in 1844 a plaster fall occurred and revealed the medieval wall paintings. Extensive and intrusive repairs following long periods of neglect can create extreme cycles that may not stabilise the building or benefit the integrity of the structure. The principle of 'little and often' should ideally be applied to historic buildings to keep them physically sound and weatherproof. Keeping a building in good condition ensures that it is able to resist the weather for its own survival and contributes towards stabilising internal conditions for the decorative wall finishes, fixtures and fittings.

Unfortunately, this was not something that happened to the chapel in the past, although since being taken under the care of English Heritage, more detailed evaluation of the more vulnerable points in the chapel that require regular and routine inspection have taken place.

Evaluation through monitoring: It is important in the complex circumstances of the chapel to consider various solutions as responses to understood causes, rather than to rush to a conclusion on the basis of slim or misleading evidence. Monitoring had established that the building had little thermal buffering, especially through the open-tiled roof, which led to almost immediate air exchange between the interior and the exterior of the building.

Diagnostic monitoring is continuing at St Leonard Chapel with the purpose of understanding the effectiveness of the new insulated roof of the chapel. Vertical profiles of conditions are being recorded at intervals from the roof to the ground in the south-east corner of the chapel in which the St George and the Dragon wall painting is located. Dependent on the results of these records, monitoring decisions will be made on the need and design of any permanent system of monitoring.

Ventilation: Ventilation is often challenging in the context of historic structures. At one extreme, sealing a historic building is both practically impossible, and can actually accelerate damage through raising internal relative humidity. At the other extreme, draughts created by open doors and windows can be equally deleterious, as they provide for almost uncontrolled air exchange.

At St Leonard Chapel, the diagnostic investigations identified that rapid exchange of moisture-laden external air through gaps in the roof, exacerbated through keeping the west door open throughout the day, resulted in periods of prolonged condensation as the air came in contact with cold internal surfaces. Immediate improvements were achieved

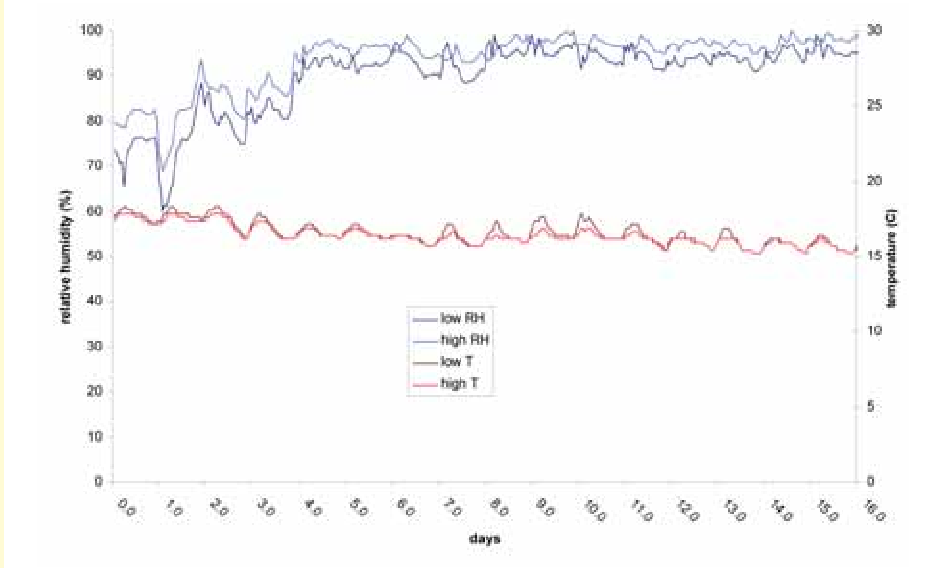


Fig 4 Relative humidity (RH) and temperature at low and high level at the wall-painting surface.

through the installation of an automatic door closure device.

Re-roofing to improve environmental stability: Previous historic roof repairs had never been deliberately designed to attempt to improve environmental conditions inside the chapel. Rather, since the late 17th century, in six programmes of repair (1610, 1780, 1840, 1900, 1930 and 1950) responded to specific damage and disrepair, largely due to periods of neglect, which included repeated partial collapse. The extent of repair ranged from nearly a complete re-roofing, to localised repair of holes in the roof. It is only the most recent, and more collaborative, building repair programme, derived from a comprehensive building condition survey in 1996, that identified the potential synergy of repairs that would provide opportunities for environmental improvement and demonstrate the importance of routine maintenance.

Reduced air infiltration was achieved through complete re-tiling and the design of internal timber boarding, which also offered a potential insulating layer to improve thermal buffering. All details were carefully considered from an aesthetic and historical perspective, and agreed with the Historic Building Inspector. The resulting stability in conditions, and the reduction in levels of high humidity entering the chapel, were designed to reduce substantially the risk of surface condensation on the wall paintings, marble tombs and other stone tombs.

Lessons learned from the Chapel of St Leonard

Integration of building, site and landscape: The two reports that were prepared in 2000 and 2003 focussed separately on the castle ruins and context, and on the chapel, respectively. These reports have been important in understanding the physical history of the individual components of the site, but not of the site as a whole. It can be difficult to make connections between parts of the heritage that ought to belong together and to analyse how problems with one might affect the other, as well as whether solving the problems in one might improve the other also. An integrated Conservation Management Plan for the whole site would ensure that environmental management addresses the relevant issues throughout the site.

Understanding cause and effect of building alterations: The need for substantive re-roofing was identified following the condition survey of the fabric, and was originally considered as part of general building maintenance. In parallel, concerns over the condition of the wall paintings, as well as other internal fixtures, highlighted the need to address environmental issues. The relative significance of the wall paintings, and the efforts made to evaluate their condition, provided the driver for improving the environment of the chapel as a whole. Most important in the development and design of the building works, these overlapping concerns prompted the need to gain an in-depth understanding of the interaction between the exterior and internal environments and the behaviour of the fabric of the building. A range of specialists from English Heritage, both regional and central, and external consultants became involved. They included architects, facilities managers, building services engineers, building scientists, conservation scientists and conservators. Through persistent collaborative working among these specialists, an integrated approach to the environmental improvements and management of the chapel gradually developed. The project not only demonstrates the need to understand the condition of the building and the environmental impacts on it through in-depth study of what is actually going on, but also the importance of a post-works review to check the efficacy and success of any intervention.

Points to consider

In summary, the following were points or steps in St Leonard Chapel project plan:

1 Understanding through in-depth interdisciplinary study the interactions between the exterior and interior environment across the different elements of the building: roof, walls and floors.

2 Implementing diagnostic monitoring in order to ensure that the causes of problems were understood before solutions are devised.

3 Ensuring that the correct range of advisers, specialists and consultants were engaged in the project and to provide the means by which they could be encouraged to collaborate effectively.

4 Identifying the potential synergy of repairs that would provide opportunities for environmental improvement.

5 Utilising the opportunity provided by intervention to demonstrate the value of routine maintenance, applying the principle of 'little and often', in order to keep historic buildings physically sound and weatherproof.

6 Maintaining the site beyond the footprint of the building in order to divert moisture problems away from the structure.

7 Undertaking a post-works review to check the efficacy and success of any intervention.

References

Padfield, T Conservation Physics. http://www.padfield.org/tim/cfys/website

Anon (ed R Gowing and R Pender 2007 All Manner of Murals. London: Archetype Publications Ltd

Ashurst, J and Dimes, F 1990 Conservation of Building and Decorative Stone. Oxford: Butterworth Heinemann

Case study 2 Brodsworth Hall, South Yorkshire

Demonstrating environmental management as an integral part of a refurbishment project

Aim

'a gentle approach' (English Heritage Commissioners and Executive Board)
To conserve and present to the public the history of Brodsworth Hall, including the effect on materials of the passage of time, by arresting years of progressive decay without destroying its special character.

The real significance of Brodsworth Hall is that it represents the evolution of a country house, not just one period, but a palimpsest, with evidence of changes through time. Because it gradually fell into disuse, Brodsworth Hall contains not only fine furnishings and fittings, but also many of the more mundane items essential to any country house.

Project outline

To further its policy of educating visitors on the evolution of the historic house, Brodsworth Hall was acquired by English Heritage in 1990. The National Heritage Memorial Fund purchased the collections and English Heritage agreed to spend the equivalent sum of money on repairs and other work, in order to be able to open the property to the public.

Brodsworth Hall was presented to show its whole history, including the effect of time, rather than try just to recapture the appearance of its earliest years.

At Brodsworth, different approaches were taken to the different elements of the project: the building itself was 'restored' – the exterior was restored in order to render it physically sound and watertight; the collections were 'conserved'; and the garden was 'developed'. Today a written conservation plan for a property earmarked for a major project is done first, to resolve in advance any tensions owing to differences in approach.
A conservation plan should ensure that proposed improvements are assessed within the context and vision for the property, and benchmarked against performance standards based on agreed conservation objectives for the whole property.

Today, Brodsworth Hall is managed jointly by two part-time curators, three visitor operations managers and two conservation cleaners. The day-to-day running of the property is hugely dependent on the work of a large group of volunteers.

Performance requirements

The aim of environmental improvements and management, once the written conservation plan was completed, was to stabilise conditions and slow down decay. Operational success was to be achieved by supplementing the existing technology within the property, with a modern environmental control system. Planning for environmental improvements had to consider the comfort needs of the small core group of staff and volunteer stewards.

Planning for comfort: In project planning terms, it is important to consider not only the environmental requirements of the building and its collections, but also how the comfort requirements of staff, volunteers and visitors will be met. It is imperative that any environmental control system for human comfort – such as heating – does not cause excessive dryness in any historic areas adjacent to staff areas.

Fig 5 Brodsworth Hall and gardens.

Solution concept: Successful conservation and presentation of a historic property, in a physical state that denotes the passage of time, requires close and constant collaboration between the curator and conservators. Materials deteriorate at different rates and the amount of conservation needs to be carefully balanced with the need to avoid visual differences between materials in the same historic room setting.

Control strategy: The need for different levels of environmental control for different uses was recognised right at the start of the project. The installation of a Building Management System (BMS) in the property was seen as key to the operational management of different areas: conservation heating in the display areas and comfort heating in the rest and services areas. A BMS consists of sophisticated engineering software that is designed to control automatically a range of environmental services including heating, cooling, ventilation, humidification and dehumidification.
Monitoring the environment through the BMS is relatively unusual because the software normally discards data after an engineer has made sure that the control equipment is operating correctly. A radio telemetry-based temperature and relative humidity, RH monitoring system was also installed to give independent verification of the performance of the BMS controlled heating. Such systems also allow placing of sensors closer to vulnerable objects, whereas the position of the wired-in sensors for the BMS can require substantial thought and compromise. Other features of a BMS can include fire detection and security protection.

The installation of a BMS improves the management of a complex building when technical support is assured. At Brodsworth Hall, the environmental control strategy involves a BMS managing relatively simple heating equipment that is intended to work in harmony with the environment and to assist the building's natural buffering capability. If a BMS is being used in an unusual way, then management needs to be aware that they will need to be more heavily involved in its operation and that external expertise may be required. Project planning must therefore consider both the capital cost of physical installation and the revenue consequences for downloading of datasets, routine environmental management and maintenance.

Maintaining the building: The consequence of neglect is rapid deterioration from water penetration and pest ingress, leading to a range of serious problems from dry rot to collapsing ceilings or floors. One of the main aims of the Brodsworth Hall project was to weather-proof the building to ensure that it is able to resist the weather for its own survival. Essential re-roofing at Brodsworth Hall took place to make the building watertight and so that later it could contribute towards stabilising internal conditions for the exhibits.

Fundamental to good management is ongoing maintenance. A building maintenance programme will ensure that these regular inspections take place and are acted upon. The asset management project presently running within English Heritage will develop building maintenance programmes, among other functions and ensure that the appropriate resources are available.

Achieving and maintaining an acceptable solution

The quality of environmental management at Brodsworth Hall was assured by a clear strategy to divide the building into environmental zones.

It is not unusual for different members on a major project such as Brodsworth Hall to have different perceptions of when a project is finished. Often the pressure to open to the public means that work continues in different areas for some time after opening to the public has actually occurred. However, unfinished work is often given lower priority after opening, and budgets may even be cut or diverted elsewhere. All essential work, particularly the commissioning, testing and handover of equipment such as the BMS, must be completed before the official opening.

The success of a project in stabilising the environment within a property, and the effectiveness of subsequent environmental management system can best be determined through diagnostic monitoring. Monitoring of internal and external relative humidity and temperature was undertaken throughout the

Fig 6 Visitors and volunteers.

Fig 7 Bedroom abandoned in 1919, conserved as found.

project. Early monitoring demonstrated the improvements in internal conditions compared to outside. This also revealed how successful the refurbishment of the building had been in reducing draughts, unwanted air infiltration and fluctuations in relative humidity and temperature, even if objects and building fabric can take several years to acclimatise to the new environment.

Information management: In projects such as Brodsworth Hall, involving several inputs, and particularly where collections are removed from the building to enable major repair work to be done, it is not only important for individuals to maintain personal records (such as logbooks, treatment and survey reports), but it is also imperative that project information is properly managed. Some of the questions that should be addressed are:

- Who is recording what information, in what form and where is it being kept?
- Who has access to individual project records?
- Do these records belong to the individual or to the property?
- Should records be held centrally, locally or in both places?
- Who is responsible for updating records?
- When should records be weeded and archived?

Records should not remain in individual files after a project is completed. To ensure operational continuity and corporate learning, an appropriate information management system should be set up.

Evaluation and feedback: All projects must be evaluated and the conclusions fed back into the organisation to allow it to learn. Best practice recommends that a project should be reviewed after different time periods. Environmental management information also needs to be assessed as part of these reviews. Although environmental effects can be rapid and obvious with highly unsuitable environments, many processes lead to gradual accumulations of damage that are insidious, and often difficult to detect, over a few years. This slow accumulation process devalues artefacts significantly in the longer term.

Evaluation and feedback assure that there is future learning, and in a climate of scarce resources, provide an opportunity to learn from one another's rich experience. By establishing a link between the first evaluation and subsequent routine condition assessment of objects and buildings, a way of monitoring the success of a project can continue indefinitely.

These reviews are in addition to a rolling programme of condition checks, routine maintenance (such as an annual 'deep-clean'), the national ten-year audit and the quinquennial survey of the historic estate, all of which will ensure that there are regular inspections of buildings and collections.

Lessons learned

At Brodsworth, opening to visitors had conservation consequences that were not foreseen during the planning process, because the project lacked the services of a dedicated conservator, a vacancy that has now been filled through the appointment of a regional conservator. When the shutters, which had not been used for years, were opened, an unexpected amount of daylight entered the property. The situation was remedied by the use of neutral density film, as well as by moveable blinds, for daylight control. Neither was there sufficient appreciation of the extent to which the fragile interior of the property would suddenly be subjected to heavy use. Part of the project management needs to be consideration of how the property will function when the project is complete and the skills, time and resources routinely available in the property to support it.

Points to consider

In summary, the following were points or steps in Brodsworth project plan:

1 Ensuring that an experienced project manager is appointed to oversee the whole conservation project including collections, building and gardens.

2 Discussing the conservation approach to be adopted by different elements of the property – collections, buildings and gardens – as soon as the project is conceived.

3 Being prepared to explain any differences in conservation approach to front-of-house staff and the public, using it as an educational opportunity.

4 Carrying out a risk assessment of the property as a whole in order to prioritise conservation needs and resources.

5 Being aware of overlaps and possible tensions among the different conservation programmes for collections, buildings and gardens.

6 Ensuring that the different programmes are clear to all in the project and those responsible for the proper on-going operation.

7 Ensuring that the level of technology that is introduced to manage the environment of the property is commensurate with the skills and resources available at the property itself.

8 Providing local training to ensure smooth running of instruments and equipment.

9 Instigating a clear policy for recording project decisions and documenting the progress of a project in order to ensure that the 'corporate memory' of a project is available to provide a learning resource for the future.

References

Richard Kerschner, R 1992 'Practical approach to environmental requirements for collections in historic buildings'. J American Instit Conservation 31, 65–76

Staniforth, S, Hayes, B and Bullock, L 1994 'Appropriate technologies for relative humidity control for museum collections housed in historic buildings'. Pre-prints of A Roy (ed) Preventive conservation: practice, theory and research. Ottawa congress, 123–128

Jeffrey, Kate (ed) 2000 Brodsworth Hall and Gardens. London: English Heritage

The National Trust 2006 Manual of Housekeeping. Oxford: Butterworth Heinemann

Case study 3 Secret Wartime Tunnels, Dover Castle, Kent

Demonstrating the multidisciplinary nature of decision making for environmental control

Aim

To understand the nature and environmental performance of the Secret Wartime Tunnels at Dover Castle, in response to a particular set of problems in order to produce a workable solution to meet the requirements of all parties.

Statement of significance

'Dover Castle is the only medieval castle to have had layers of tunnels excavated under it during the Second World War to form a Combined Headquarters and a Forward Dressing Station … The castle also had a Regional Seat of Government [set up within the tunnels], which functioned from c *1962 to 1984 and which still contains significant amounts of contemporary equipment.'* ('Dover Castle the key to England: a conservation statement', Jonathan Coad, revised March 2004, English Heritage).

The role of the wartime tunnels in national affairs during the Second World War has

Fig 8 Secret wartime tunnels

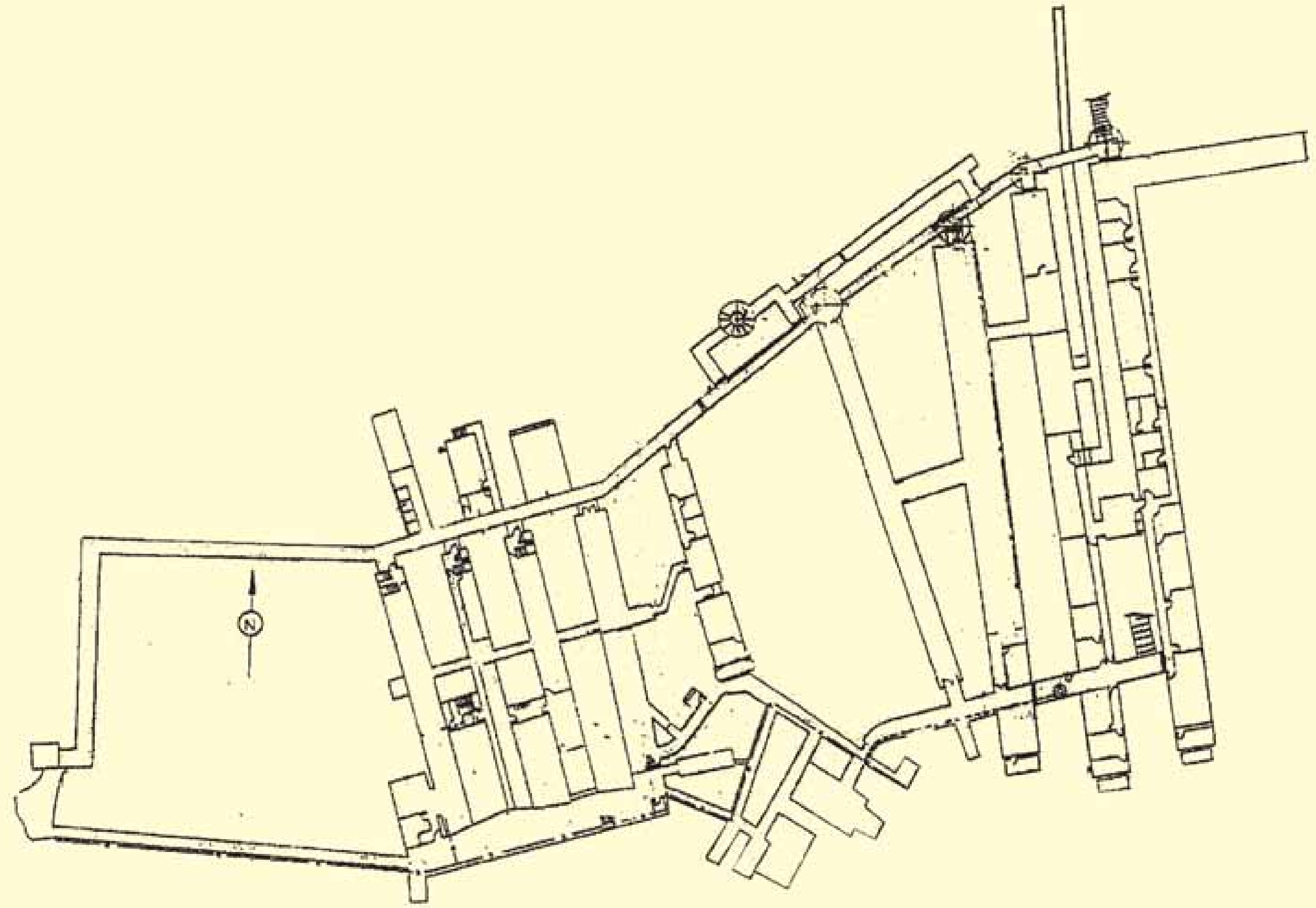


Fig 9 Plan of Casemate Level.

contributed significantly to the long and stirring history of Dover Castle. The tunnels survive as a unique testament to military planning, defence and operations, as part of the forward operations centre for the eventual invasion of northern Europe on June 6,1944.

Project outline

To further English Heritage's duty to preserve one of its most visited and significant monuments, and to maintain a safe environment for visitors and staff.

Performance requirements

Site description: Some of the chalk wartime tunnels are lined either with brick or with steel. The Napoleonic Casemate barracks were extended and two other levels of tunnels, known as Dumpy and Annex, were constructed to house the operations headquarters and an underground hospital. The tunnels at Casemate contain features and items of equipment known to have remained in place since their original installation when the tunnels became operational. Annex accommodates a rare example of a British underground military hospital, although its original equipment had been removed and it is now fitted out with contemporary equipment from other collections.

Presentation and interpretation: The objectives for the presentation of the Secret Wartime Tunnels could be described as follows:

- To communicate the history of the tunnels within the context of Dover Castle.
- To highlight significant historical developments that are associated with major events in history.
- To demonstrate important architectural and civil engineering advances that are unique to this site.
- To keep technological interventions for lighting and environmental control to a minimum, and to maintain the quality of the interior fixtures and fittings.
- To sustain continued use of historic objects, which are essential to the presentation and understanding of the spaces.
- To maintain the fabric and collections in a sympathetic way, while controlling relative humidity (RH), ventilation and temperature.
- To enhance the interest and the educational relevance of the tunnels to a wide range of visitors, while reducing the adverse impact of these visits on the tunnels.

Solution concept: The tunnels contain a variety of historic artefacts made from a range of materials. They are, in themselves, a complex environment with various ventilation routes. Natural ventilation was improved using original fans and ducting. However, it was decided to turn off the fans in the Casemate level and to rely on natural ventilation, prompted by the continued mechanical failure of that plant. In 2001 a spectacular outbreak of mould growth in those tunnels occurred, which appeared to be the result of this action. Investigations were undertaken to understand and solve the environmental problems.

Control strategy: An environmental control strategy must be based on an in-depth understanding of natural and deliberate changes that have occurred in the tunnels and systems in the past. The following measures summarise the process of developing a control strategy:

- Bring together key local, regional and central English Heritage staff and their consultants to develop a coherent action plan.
- Understand and communicate in full the inherent features and condition of the structure that promote environmental stability, including responses to weather conditions.
- Understand and communicate the impact of change to links between spaces within the tunnels, and how this might affect environmental stability. Explain how open doors encourage natural airflow, the importance of which was not fully appreciated.
- Understand and communicate the wider impact of changes in the operation of ventilation equipment, and how it might affect human health and comfort.
- Ensure that solutions, whether technologically sophisticated or simple, can be operated easily by staff without a large extra burden.

Any control strategy needs to be sustained by an effective monitoring, renewal and maintenance programme.

To address the mould problem, from 2001the South East Region of English Heritage instigated a multidisciplinary action plan involving key local, regional and central staff and consultants. It commissioned a number of key technical studies to characterise the environment in the tunnels:

- a microbial and building health survey;
- environmental risk assessment studies;
- and an environmental monitoring survey.

The results of these studies demonstrate the complexity of resolving environmental risks surrounding the tunnels and their contents, staff health and comfort and the demand on resources.

Achieving and maintaining an acceptable solution

It is important to define what is 'an acceptable solution' in the context of the tunnels. High RH can encourage rapid mould growth, and therefore mechanical ventilation was re-instated in the Casemate tunnels to make the environment less conducive to mould growth. The following measures were taken:

- Airborne mould was sampled and identified.
- Effective cleaning regimes were introduced to reduce the level of mould spores in the air, and the importance of maintaining a good housekeeping regime emphasised.
- Every infected object was removed from the affected area, and cleaned in a controlled manner.
- Monitoring the moisture profiles from the tunnel walls confirmed that evaporation would generate high RHs if there was insufficient ventilation to carry the moisture away.
- Air flows in critical areas were measured and improved where necessary. Many moulds have been found unable to germinate their spores and grow in air velocities greater than 0.2m-?, even at very high RH.

Natural ventilation or mechanical ventilation?: Ventilation is often a challenging issue in the context of an enclosed historic site. Natural air currents are not an acceptable alternative to controlled ventilation, while neither is sealing an occupied and lit space to control RH and temperature, or to prevent the ingress of dust, air pollution and pests. Inadequate ventilation can result in potentially damaging high levels of RH and harmful carbon dioxide levels. Relying solely on natural air exchange between the exterior and interior seeping through cracks and gaps in the fabric has often been found to be inadequate, while opening windows is not an acceptable solution because of safety, security and pollution risks, and its adverse effect on the stability of the indoor environment. Instead, controlled ventilation can be achieved by:

- mechanically assisted natural ventilation – the installation of fans in unobtrusive places to draw air from or into an interior;
- and by mechanical ventilation – the installation of fans, filters, ductwork and perhaps also heaters and coolers to condition the air before it is supplied to an interior. (A historic ductwork system already existed in the Secret Wartime Tunnels, so this could be utilised.)

In comparing these two options, the extent of potential control, invasiveness to the building fabric and cost were found to be different: the first option moderates natural conditions less invasively and less expensively than the second option. The first option has also been tried elsewhere with some success, while the second is generally considered to be intrusive to a historic site. The level of

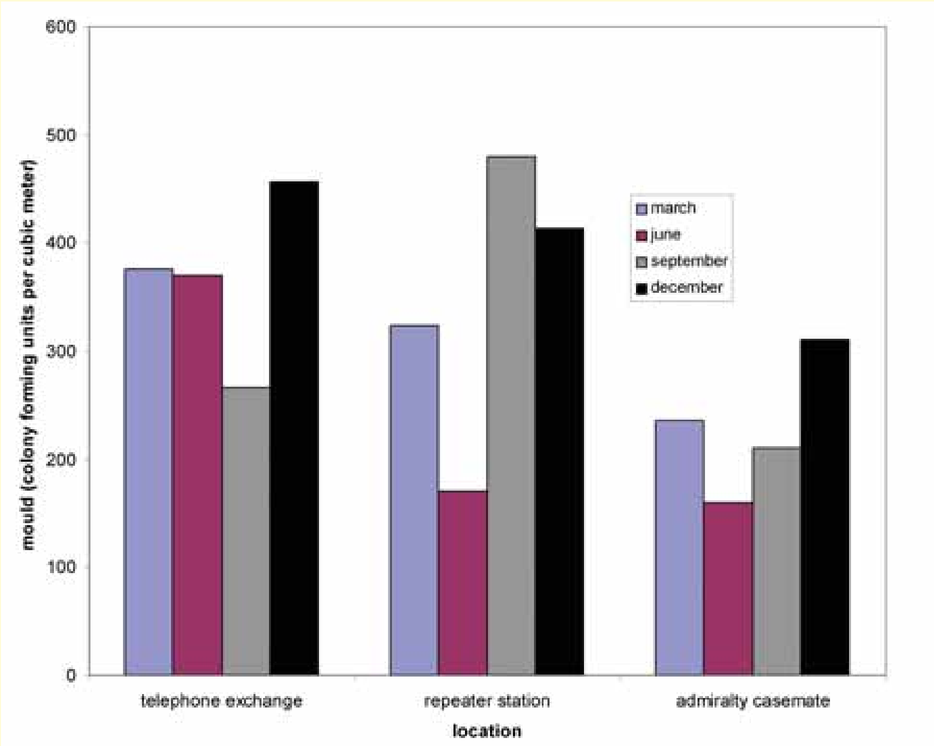


Fig 10 (above) Mould growth on telephone exchanges and under plotting table.
Fig 11 (right) Mould growth on telephone exchanges and under plotting table.

Receiver: Stone Hut

Transmitter	Type	Ch 1	Ch 2	Alarms		Battery	Status	View...
[00] External	HygroClip 16-bit	10.0 °C	97 %RH	LL	HH	OK	OK	
[01] Telephone Exchange	HygroClip 16-bit	15.3 °C	73 %RH	L	H	OK	OK	
[02] Naval Ops	HygroClip 16-bit	13.3 °C	82 %RH	L	H	OK	OK	
[03] Gun Ops	HygroClip 16-bit	13.7 °C	77 %RH	L	H	OK	OK	
[04] Repeater Station Back	HygroClip 16-bit	13.7 °C	81 %RH	L	H	OK	OK	
[05] Picture Gallery TP2	HygroClip 16-bit	16.0 °C	86 %RH	OK	HH	OK	OK	
[06] Battery Passage Back	HygroClip 16-bit	15.9 °C	79 %RH	L	H	OK	OK	
[07] Battery Passage Front	HygroClip 16-bit	15.9 °C	77 %RH	L	H	OK	OK	
[08] Guard Room	HygroClip 16-bit	15.2 °C	76 %RH	L	H	OK	OK	
[09] Mess	HygroClip 16-bit	18.1 °C	66 %RH	OK	OK	OK	OK	
[10] Reception	HygroClip 16-bit	16.1 °C	79 %RH	OK	H	OK	OK	
[11] Kitchen	HygroClip 16-bit	17.2 °C	70 %RH	OK	OK	OK	OK	
[12] Dorm	HygroClip 16-bit	18.2 °C	67 %RH	OK	OK	OK	OK	
[13] Central Gallery	HygroClip 16-bit	17.1 °C	70 %RH	OK	H	OK	OK	
[14] Ward 1	HygroClip 16-bit	17.1 °C	67 %RH	OK	OK	OK	OK	
[15] Ward 2	HygroClip 16-bit	17.8 °C	62 %RH	OK	OK	OK	OK	
[16] Operating Theatre	HygroClip 16-bit	17.1 °C	70 %RH	OK	H	OK	OK	
[17] Picture Gallery Middle	HygroClip 16-bit	16.8 °C	73 %RH	OK	H	OK	OK	
[18] Picture Gallery End Nr Lift Lobby	HygroClip 16-bit	17.1 °C	72 %RH	OK	H	OK	OK	

Fig 12 (above) Original ventilation ductwork in tunnel casemate.
Fig 13 (right) Environmental Conditions in the tunnels; screen shot of part of the wireless monitoring system.

ventilation control promised by the second option is theoretically greater, but in practice the risk of a breakdown in equipment, and the subsequent cause of environmental fluctuations may be unacceptable.

Re-instating the original mechanical ventilation in the tunnels in the Casement level was considered an acceptable way forward. This ensured that the airflow could be better controlled and that the fluctuating conditions experienced with the natural ventilation system would be reduced. Additionally the ventilation system was considered appropriate to the authentic atmosphere of the Tunnels.

Maintenance of the fabric: In this instance it is impossible to maintain 'museum' conditions for the collections material without causing serious damage to the chalk tunnels. Significant heating or dehumidification would lower the RH, but increase the flow of moisture through the chalk. The condition of the chalk tunnel fabric is managed through regular monitoring and maintenance. The following table identifies the major issues:

vulnerabilities	*specific issues and concerns*
walls and roof	leaks through the porous chalk substrata
collection items	damage from mould growth and high RH levels
site team and visitors	cold, damp and draughty conditions in winter, health risks from mould

Cleaning of objects infected by mould: Once a mould outbreak has occurred, the affected objects must be thoroughly cleaned. This can be a time-consuming and costly exercise. The large amount of complex wiring in period telephone exchanges required specialist equipment for cleaning. It is important that this significant investment is not wasted and that an ongoing cleaning regime is put in place to keep objects and the tunnel environment clean and free from the risk of further outbreaks of mould.

Monitoring: Monitoring of airflow, RH and temperature, and diagnostic studies of mould growth have been essential to understand the environmental conditions within the tunnels. It is important to realise that the weather, geology and resulting moisture levels in the chalk heavily influence the tunnel environment.

A real-time monitoring system has been installed to give early warning of conditions conducive to mould spore germination. It will also enable a more pro-active approach to be taken with the management and maintenance of the tunnels and their collections.

Lessons learned

The biggest lesson that can be learned from the Secret Wartime Tunnels project is that no single discipline on its own could have solved the problem. Everyone was concerned about the problem for different reasons:

• staff were concerned about health issues;
• curators and conservators were concerned about the objects;
• and facilities managers were concerned about the condition of the chalk fabric.

A solution was developed through constructive team working, bringing together several disciplines and strands of expert advice. Open discussion of past experience enabled lessons to be learned. All parties worked together to find an acceptable solution to the problems that existed at that time, respecting each other's areas of expertise and knowledge, and not attempting to allocate 'blame' or to criticise past decisions, which had been based on the best available information at the time.

Points to consider

In summary, the following were points or steps in Secret Wartime Tunnels project plan:

1 Accepting that there may be situations and locations where environmental management will be challenging and that the best efforts might only achieve modest improvements.

2 Recognising that 'museum' conditions for collections may cause serious damage to unusual structures, such as chalk tunnels.

3 Understanding that the best solutions are developed through constructive team working to bring together unusual strands of expertise, such as mould identification.

4 Remembering that environment management often requires complex decision-making, centred around risk reduction of damage to shelters and to the collections, staff, and visitor health and comfort within the context of available resources.

5 Being open to advice from a variety of sources, both internal and external, while critically evaluating the benefits.

6 Ensuring that an environmental control strategy is based on an in-depth understanding of the natural and deliberate changes that occurred to the shelter systems in the past.

References and further reading

Florian, M L 1997 Heritage Eaters. London: James and James

English Heritage 2008 Conservation Principles. http://www.english-heritage.org.uk/server/show/ConWebDoc.13556

English Heritage 1999 Conservation Plans in Action. London: Proceedings of the Oxford Conference

Case study 4 Royal Garrison Artillery Barracks, Dover Castle

Demonstrating environmental control for storing archaeological and historic material in a building not constructed for this purpose

Aim

To understand the nature and performance of Royal Garrison Artillery Barracks at Dover Castle, and its suitability for the storage of collections.

Statement of significance

The Royal Garrison Artillery Barracks, are one of the most recent barracks to survive at Dover. They are important for their link with coastal artillery, specifically to man coast batteries. The interior of the barracks is capable of sympathetic adaptation to collection storage.

Project outline

Mission: The Royal Garrison Artillery Barracks have been used almost unaltered as a regional store for archaeological and more recent material since the mid-1970s. This material is available for study by appointment to external researchers and is a rich resource for English Heritage local, regional and central staff. A study room has recently been provided for this purpose.

Function: To further English Heritage's duty to manage its collections, while making minimal impact on the building in an effort to improve environmental conditions. The material stored in the Royal Garrison Artillery Barracks consists of small boxed archaeological finds, large archaeological finds, architectural reference materials, 20th-century artefacts (particularly from the Second World War and the Cold War), textiles and paper archives, including many archaeological plans from the south-east region of England.

Performance requirements

Site description: The Royal Garrison Artillery Barracks store is an early 20th-century stone building constructed originally as accommodation barracks. As such, it has rows of sash windows on both storeys at each elevation. The building is orientated north–south, with the south-facing elevation orientated towards the English Channel. The timber windows frames on the south-facing elevation show signs of the ravages of the weather, in particular from salt-laden wind, rain and sun. The interior of the building is a combination of open plan and smaller rooms, with solid floors, which makes it suited for storing heavy objects on the ground floor. Solar heat gain in the south-facing rooms is not a problem because the windows are shaded and the more environmentally sensitive materials – such as the archives and modern materials associated with 20th-century artefacts are stored in the rooms that face north.

Storage: Before solution concept and control strategies can be developed, the conditions required by the stored material need to be assessed. This can be a complex process for archaeological collections, as their burial conditions and history can make objects of the same material type have a range of stabilities. For example, limestone laden with salt from burial is easily damaged by fluctuating relative humidity (RH), whereas a similar limestone with little or no salt is less vulnerable. The storage strategy is best informed with information about:

• the collections to be housed, and any plans for expansion or new acquisition;
• internal storage boxes and systems;
• the condition and buffering capacity of the building;
• available studies and internal environmental monitoring data;
• localised and centralised environmental improvements;
• use patterns and duration;
• and external weather conditions in particular rain, particularly wind-driven rain, solar radiation, wind speed and wind direction.

The priorities for the regional archaeological store could be described as follows:

• To make the collections safe and accessible to a wider range of users.
• To complete the documentation of the collections.
• To provide the environmental conditions appropriate to the different stored materials.
• To monitor RH and temperature, to analyse the data and to act upon on the information.
• To implement an integrated pest management plan.

Solution concept: The nature of the structure and its limitations need to be assessed in order to design the right control strategy. The building has a number of large windows and sunlight could cause seasonal heating of the interior air. The poor condition of the timber on the south-facing windows will allow ingress of air, dust and transport pollution, and could allow insect pests to enter the store. It is also important to assess the vulnerability of the stored collections, and ideally to assign them to rooms known to provide the best environments for their protection. The most vulnerable elements of the stored collections were considered to be the Second World War and Cold War collections and archives. These are stored in the rooms that face north, have windows in the best condition, and hence the best buffered, and receive the least solar gain.

Control strategy: An environmental control strategy must be based on an in-depth

Fig 14 (left) The Royal Garrison store at Dover Castle.
Fig 15 (above) The enclosed entrance at the barracks creates a wind vortex, which deposits wind-driven rain onto these walls. Therefore, no collections are stored inside (on the opposite side) directly against these damp walls.

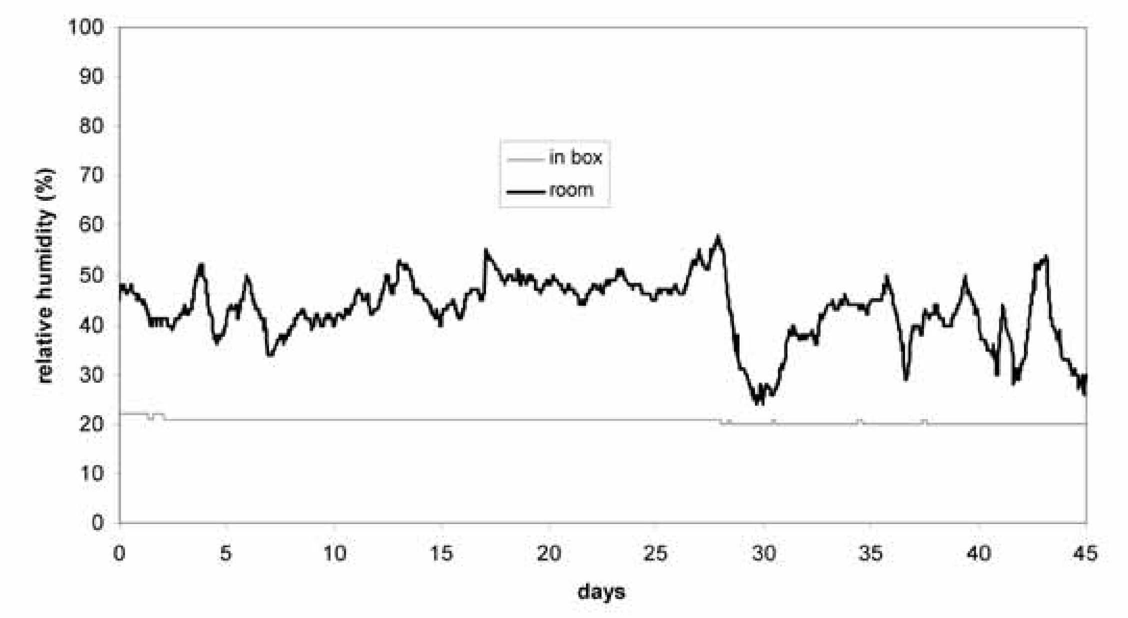


Fig 16 The relative humidity (RH) inside polypropylene boxes is reduced to below 30% by the addition of sufficient dried silica gel. The room RH is kept below 50% with a dehumidifier, which significantly extends the period between changes of the silica gel.

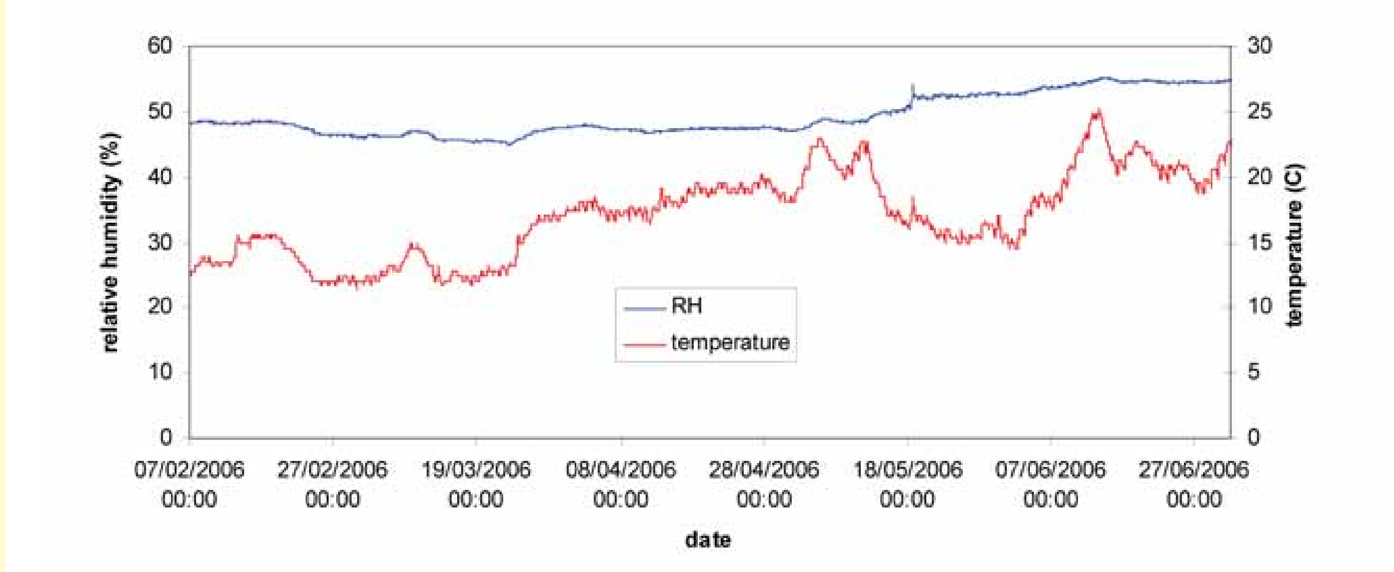


Fig 17 The relative humidity (RH) in the archive room is adequately controlled with a manually adjusted radiator, turning it up or down depending on the reading from the radio-telemetry monitoring system.the silica gel.

understanding of the prevailing conditions in the building, and include steps to control the factors that influence them. The following 13 measures summarise the process of developing a control strategy for a storage building:

1 Examining the condition of the building, particularly the walls and windows most exposed to the prevailing weather (especially wind driven, salt-laden rain) that can infiltrate the building through weak points such as badly fitting windows.

2 Assessing the condition and capacity of the rainwater goods, including gutters and down pipes, in order to avoid the wetting of walls.

3 Ensuring through thorough maintenance that rainwater and groundwater is carried away from the building.

4 Checking that groundwater is not penetrating into the storage areas or into the building fabric.

5 The previous four factors can all lead to wet walls. It is important that if rooms with wet walls have to be used for storage, that sufficient gap is left between the interior of the wall and the collections to enable air circulation.

6 Deciding on the preventive conservation threats that present the greatest risk to the stored materials.

7 Undertaking routine inspection for pests and thorough cleaning of surfaces.

8 Deciding whether diagnostic, alarm-based or routine monitoring is required.

9 Undertaking routine sample condition checks and documenting the stored collections, concentrating on the materials known to be at greatest risk from the most severe threats.

10 Implementing an approach to environmental control in the building that is appropriate to the available time and skill of the staff.

11 Ensuring that materials vulnerable to poor environmental conditions are stored in the most stable parts of the building.

12 Adding additional environmental control to some rooms to provide more suitable environments.
13 Providing additional protection and stability for environmentally sensitive items through the use of passively controlled microclimates within boxes.

A control strategy can only be sustained through an effective renewal and maintenance programme, with resources allocated according to local needs and regional priorities.

Achieving and maintaining an acceptable solution

Maintenance of the fabric: When dealing with a store in a historic building, it is imperative that the requirements of the building are not forgotten. The building must be kept weatherproofed by ensuring that it is kept in good condition, following its original design and construction. In this way the building is able to resist the weather for its own survival and contribute towards stabilising internal conditions for the stored items.

Heating and dehumidification: Monitoring of the environment in the Royal Garrison Artillery Barracks has shown that the RH is generally high. The RH is currently controlled by a combination of heating and stand-alone dehumidifiers. This solution using low technological control has much to recommend it, although it is important to remember that some types of dehumidifiers need plumbing into the drain system to avoid flooding. Conservation heating is used in the archive room and stabilises RH between 51% and 65%, with the temperature at about 6°C higher than outside temperature during winter. However, this approach needs to be balanced against the potential to increase the deterioration rate of the paper by raising the temperature. In the winter the temperatures are often too low for human comfort, and other methods, such as warm clothing or local heating, will be required if staff are to work in that area. However, the archive room is not habitually occupied.
Microclimates: The building's natural RH is much too high for vulnerable archaeological metals, such as iron or copper alloy. Microclimates can be achieved in polypropylene boxes buffered with dry or conditioned silica gel. These provide reliable and relatively low-maintenance control of the environment immediately around the artefacts.

Zoning: All buildings have natural environmental zones that behave differently owing to their orientation on the site, the size of glazed areas, the volume of the spaces and the amount of air exchange with the exterior. Environmental zoning can be used deliberately in the management of a property. Diagnostic monitoring may reveal that the environment of a store could be improved if the spaces were to be divided into a number of manageable environmental zones, bearing in mind the following points:

• that the ambient zone that staff and visitors occupy could be conditioned similar to domestic premises, includes the study room and offices;
• that the microclimates described above collectively make up the tightly controlled zone for sensitive objects;
• and that the differently oriented faces of the building create different environmental conditions (for example, the north face is more stable and the south face is less stable).

By taking advantage of naturally occurring conditions, additional control is made simpler and cheaper.

Alarm-based monitoring: Currently, monitoring consists of a couple of decades' experience of observing changes in objects and intermittent checks of particular problem areas, or areas with vulnerable materials, using dataloggers and thermohygrographs. Condition checks of the collections, the building and the environment also take place as part of the national audit of collections every ten years. The archaeological materials have been in storage for long enough to be known to be stable, but because the paper archive and textile store are relatively recent, regular monitoring should focus on these last two.

Diagnostic monitoring is currently underway using dataloggers. A discreet wireless telemetric data logging system to monitor RH and temperature has been acquired for the store and the site as a whole.

Considerations for the future

Staff resources: The pressure of work on a small staff limits the time that can be dedicated to routine environmental and collection management, including monitoring, condition checks, documentation and repacking. Although additional resources can be pulled together for special projects, the available time for routine tasks can dwindle in the face of requests for information, research, organising exhibitions and administration. It is therefore important to draw up a management plan for each store, and that one person is given overall responsibility and the resources to implement the plan.

Points to consider

In summary, the following were points or steps in Royal Garrison Artillery Barracks project plan:

1 Drawing up a management plan for the store in order to overcome the inevitable peaks caused by other projects.

2 Improving the environmental stability of the building fabric, with due care for the structure, before introducing technological improvements.

3 Giving one person overall responsibility and the resources to implement the plan.

4 That environmental monitoring data can be analysed using psychrometry to assess changes in moisture content and aid in the design of appropriate solutions to environmental control.

5 Considering the usefulness of zoning spaces and that creating microclimates in boxes is integral to environmental management with minimal energy input.

6 Understanding the advantages and disadvantages of heating and dehumidification to reduce RH in stores.

7 Assessing the condition and future use of stored collections in order to establish their vulnerability and environmental management options.

References

Brown, D 2007 Archaeological Archives: a Guide to Best Practice in Creation, Compilation, Transfer and Curation. Archaeological Archives Forum: http://www.archaeologists.net/modules/icontent/index.php [downloaded 10 August 2007]

Thickett, D and Odlyha, M 2005 'Storage of archaeological iron'. Post-prints of The Conservation of Archaeological Materials, Williamsburg, Virginia, 13–18 November 2005

Thickett, D, Rhee, S and Lambarth, S 2007 'Libraries and archives in historic buildings', in T Padfield and K Borchersen (eds) Museum Microclimates. Hvidovre: L P Nielsen Bogtryk, 145–56

Fig 18 Chiswick House.

Case study 5 Chiswick House, London

Demonstrating environmental management in a historic property used for private hire for events

Aim

To balance the management of Chiswick House and its collections with the needs of private hire, public access and conservation. When considering the suitability of a property for events, many things other than the environment need to be evaluated, such as catering, food preparation, choice of contractor, other facilities, such as toilets, electrical supplies, and fire safety. For further information see Practical Conservation Guidelines for Successful Hospitality Events in Historic Houses, published by English Heritage (2004).

Statement of significance

"Chiswick House, built between 1726 and 1729, is one of the earliest and most important neo-Palladian villas in England." (Chiswick House and Gardens, London, English Heritage)

Whether Lord Burlington knew or not, in building Chiswick House in the Palladian style, he adopted a design that in its origin had specific environmental performance characteristics.

Project outline

"The house was intended as a temple to hospitality, and in its heyday the lavish rooms witnessed many glamorous events as the Burlington dynasty entertained the artists, politicians, and leading figures of London high society." (http://www.english-heritage.org.uk HOME>HIRING A VENUE>LONDON PROPERTIES>CHISWICK HOUSE)

Chiswick House is the first 18th-century Palladian villa in the country. http://www.english-heritage.org.uk/Filestore/hospitality/chiswick/chiswick_courtyard.jpg. The magnificent interiors – with gilded decorations, paintings and period furnishings – provide a unique setting for private and corporate events. The balcony doors open onto 18th-century landscaping; and classical Italianate gardens adorned with temples, statues and lake.

Staffing: Many additional staff are employed during private events. This requires careful scrutiny of external suppliers and contractors in preparation, during the event, and when dismantling any special arrangements put in place, such as moving of furniture by our trained staff.

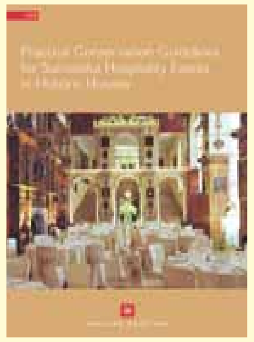
Performance requirements

Site description: 'The plan has two suites of apartments around an octagonal domed saloon with a sequence of variously shaped (sumptuous and colourful reception) rooms, round, octagonal and apsidal-ended. On the exterior, tastefully selected openings punctuate the neutral wall surface. The recessed Venetian windows of the rear façade were to have a long history in Palladian building'. – Sir Banister Fletcher (A History of Architecture. 1996, Architectural Press, London).

William Kent was responsible for much of Chiswick House's interior decoration. Furniture originally designed by Kent for the house is gradually being returned (see http://www.chfriends.org.uk/).

Comfort of Occupants: While most properties can achieve a degree of environmental control for normal visitor opening, private events pose a different set of challenges. For example, a large numbers of guests accommodated in a single room will generate greater than average heat and humidity. A seated dinner function in winter will require a higher temperature for comfort than that required for casual daytime visitors walking around the property. Functions with dancing may require cooler conditions; and the vibration that may cause damage to the structure will also need to be considered. Additionally, clothing worn for some events is likely to be lighter weight than everyday clothing, and therefore increased heating may be required. In contrast, such additional heating may be offset by the greater number of people who might attend stand-up receptions.

Fig 19 'Practical Conservation Guidelines for Successful Hospitality Events in Historic Houses', published by English Heritage in 2004.

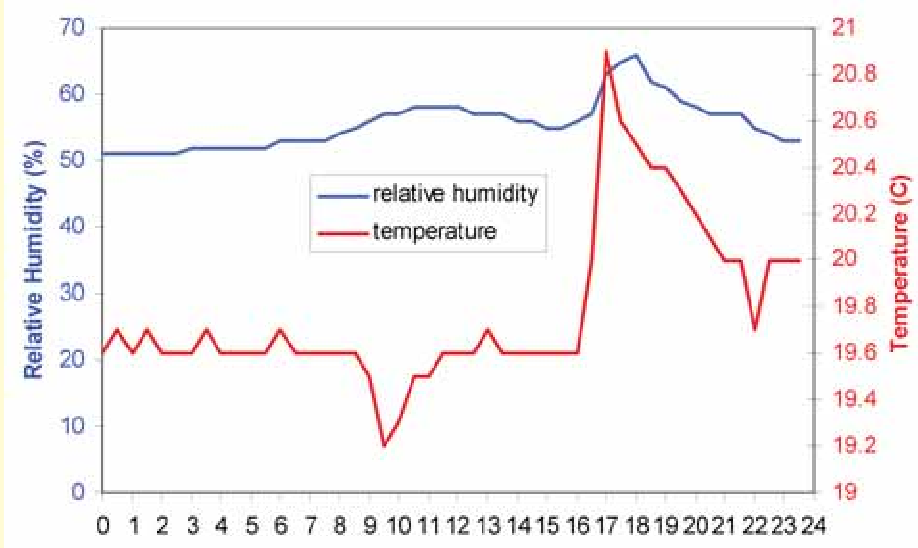


When Chiswick House is used as a venue for events, the aim is:

- to give a sense of splendour for hospitality, corporate and private functions, thus ensuring that a memorable occasion is had by everyone;
- to ensure that appropriate measures are in place to protect the furnishings, fittings and other vulnerable surfaces during functions (low-level paintings are glazed, perspex covers are placed on vulnerable horizontal surfaces and some furniture is stanchioned off or moved out of the way or into temporary storage);
- to provide comfortable conditions for the guests of Chiswick House;
- to manage the numbers of guests at any one time, in order to protect the property from excessive wear and tear;
- and to assess the impact of different functions on the conservation of Chiswick House.

Solution concept: Ambient temperature, relative humidity and ventilation need to be controlled during functions, both for the comfort of attendants and the protection of the room interiors. The impact on the internal environmental conditions of opening windows needs to be assessed and managed. Until relatively recently, heating systems in historic properties were not designed to deal with the demands of busy functions. Furthermore, the existing warm air heating system at Chiswick House causes large temperature differences across the building, with a 7°C difference having been recorded.

Control strategy: English Heritage manages other risks associated with the organisation of hospitality events by issuing a publication entitled 'Practical Conservation Guidelines for Successful Hospitality Events in Historic Houses' as well as a Memorandum of Agreement for each event. English Heritage works with a limited number of vetted caterers and suppliers in order to reduce the risk from pest infestation caused by the serving of food, inadequate cleaning or waste disposal. The ground and the first floors of Chiswick



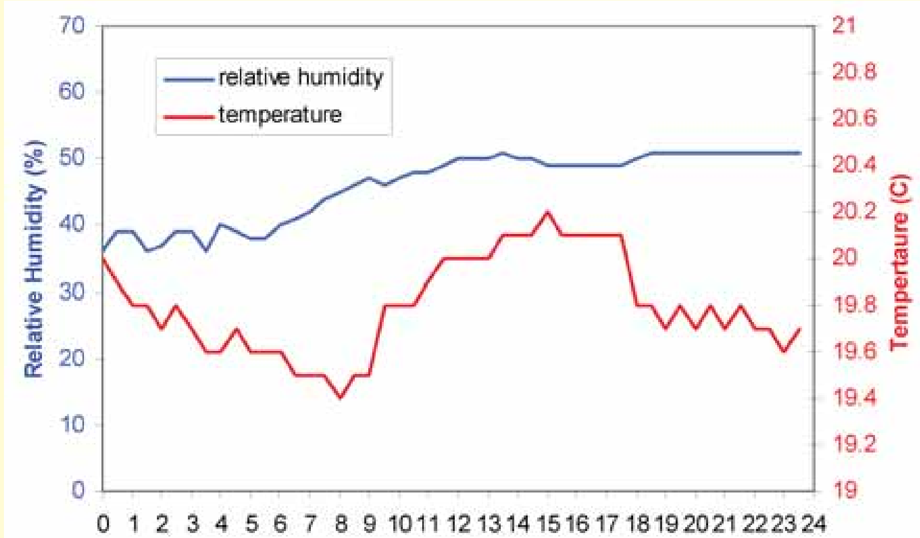


Fig 20 (top) Wedding between 16:00 and 23:00: daily trace of temperature and relative humidity generates spike a in the temperature and shows great relative humidity (RH) variability.
Fig 21 (bottom) A day at Chiswick House with normal opening for comparison.

House are both at risk from stains caused by spillages of food and drink and wear and tear from use. The carpets on the first floor, while appearing authentic, are intended as sacrificial surfaces to soak up spillages.

Post-function reports are written and questionnaires are completed after every event in order to evaluate their costs and benefits. Yet it is environmental management issues that are often the most intractable in a historic property. Chiswick House is known to have high air-infiltration rates and diagnostic monitoring has shown significant fluctuations in relative humidity (RH) to occur.

A typical function increases the RH by 15% and the temperature by 5°C, which is similar to the natural fluctuations experienced in these rooms. However, event-driven fluctuations of this magnitude may cause damage in other properties.

Achieving and maintaining acceptable conditions

"I can imagine that providing a listed building as beautiful as Chiswick House as a function venue can be a difficult task to manage with all the understandable restrictions and excited clients and suppliers and you do this very well." (A happy wedding couple, August 2003)

Fundamental to good management is good maintenance; and this is even more so in a historic property that is used for external events where the appearance of the property is an important factor in its public appeal. A building maintenance programme should ensure that these regular inspections and corrective measures take place. This is essential if acceptable conditions are to be achieved and maintained.

Heating and cooling: In English Heritage properties, the fires are usually unused and the chimneys are normally capped. Ventilated capping ensures air flow through the chimney to avoid the risk of rain ingress, damp penetration, disintegration of the flue lining or pest infestation. Alternatively, rather than remaining unused, the chimney flues could be converted for use as vertical ducts to improve the distribution of conditioned air by allowing it to diffuse throughout the space and be vented out of the building by natural or assisted means.

Sealing a historic building can damage the fabric and the interiors, and it could contravene legislation that requires minimum ventilation for the health and comfort of occupants. Ventilation is particularly challenging in buildings where the level of occupancy can vary considerably between events and times when there are only staff on the premises. The quality that makes natural ventilation in a historic building desirable becomes a problem when the building has a large gathering in it. In such circumstances it is inevitable that ventilation will need some mechanical assistance.

Zoning: All buildings have natural environmental zones that behave differently due to their orientation on the site, the size of glazed areas, the volume of the spaces and the amount of air exchange with the exterior. The environmental differences can be accentuated by the activities that take place in the different spaces. Therefore, environmental zoning can be used deliberately in the environmental management of a property.

Chiswick House can be considered as two environmental zones: the first floor, containing the decorative finishes and sensitive objects; and the ground floor, which contains less sensitive objects. Activities that have a high impact on the environment, such as cooking and dancing, are only allowed in specific rooms on the ground floor.

Monitoring: Diagnostic monitoring of temperature and relative humidity can help evaluate the effects of functions and their impact on collections and interiors. When occupancy can influence environmental conditions, it may be advisable to monitor another environmental parameter, namely carbon dioxide, before, during and after functions, in order to establish the adequacy of ventilation provision.

Future actions

Working with the building: Opening doors and windows to improve ventilation moves large volumes of air into the building and with it dust, other pollutants and pests. Traditional buildings as environmental systems behave very differently to modern buildings, and therefore the building design and the environmental behaviour of any architectural precedents should be investigated in order to understand how they worked before trying to improve their performance with new equipment.

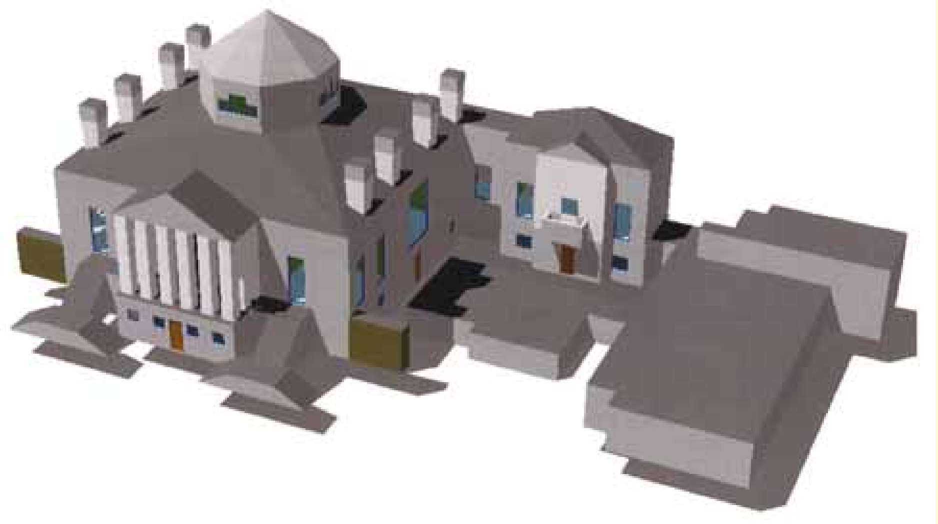


Fig 22 Hygrothermal computer model of Chiswick house.

Burlington modelled Chiswick House on the design of Palladian villas, where thermal windows and doors are known to have been opened to encourage air flow and to alleviate the oppressive heat of the Italian Veneto.

Currently the thermal windows at Chiswick House are kept closed because of concerns that wind-driven rain could damage the paintings hanging in the octagonal saloon and could allow the ingress of pests such as insects, squirrels, mice and birds. The use of Chiswick House today is very similar to the use for which it was originally designed. The regulations that govern human comfort and the environmental factors that must be controlled to protect interiors and furnishings in a historic property need to be clearly understood.

Understanding the architectural history of a site can also help to ensure that the environmental control potential of the building fabric is exploited as part of any design decisions. A computer model has been generated of Chiswick House, and it will be used to test proposed heating strategies for a complete refit of the services. It is not a change in use that often necessitates the use of technology to boost the inherent design features of a building that was originally designed for hospitality, but rather the expectations and regulations that govern human comfort and health in buildings today. Too often a technological solution for an environmental problem is suggested before the building and its inherent environmental design features have been considered.

Points to consider

In summary, the following points should be considered for historic buildings used for events:

1 Ensuring that reputable contractors, with experience in working in historic properties, are engaged.

2 Taking nothing for granted – the most invisible of all risks, the impact on the stability of relative humidity and temperature of high occupancy, also needs to be managed.

3 Working out the carrying capacity of the property for different events – and stick to it.

4 Working out how the occupancy load can be diffused over space and time.

5 Ensuring that all property staff are trained to anticipate and to minimise risks of damage either human or from the environment.

6 Communicating your instructions clearly through methods that are most appropriate for the different recipients of it.

References and further information

English Heritage 2004 Practical Conservation Guidelines for Successful Hospitality Events in Historic Houses. London: English Heritage

Geva, A 2005 'The use of computerised energy simulations in assessing thermal comfort and energy performance in historic buildings'. Structural studies, repairs and maintenance of heritage architecture IX, 587–96

Case Study 6 Ranger's House, Blackheath

Demonstrating environmental control for a museum-type exhibition in a historic property

To display and interpret the Wernher Collection on loan to English Heritage at Ranger's House. Ranger's House aims to give visitors a stimulating and engaging experience of works of art of great variety and an insight into the life of Sir Julius Wernher.

Aim

'We hope that this presentation will encourage new and diverse audiences to learn more about Europe's rich culture of Decorative art.' (Dr Simon Thurley)

Functional statement

'The objects themselves are beautiful and extraordinary in equal measure, demanding an inspired installation and display of the highest standards.' (Dr Simon Thurley)

Function: To further English Heritage's policy of enhancing its historic houses for visitors, and to save the Wernher Collection from dispersal after the closure of Luton Hoo in 1998. English Heritage negotiated a 125-year loan with the Wernher Foundation, a charitable trust, for the collection to go on public view at Ranger's House.

Performance requirements

'Each vitrine must be like a picture.' (Sir Julius Wernher)

Presentation and interpretation: The presentation of the Wernher Collection at Ranger's House recreates an elegant 18th-century interior on the ground floor and a museum exhibition on the upper floor, the latter being the focus of this case study. The museum exhibition represents Sir Julius's museum room in Bath House, with its Renaissance-style furniture, Old Master paintings, gothic ivories, Renaissance bronzes, finely detailed enamels, majolica and other 'objets d'art'. English Heritage generally prefers displays in its properties uninterrupted by display cases. Nevertheless where required, display cases are used to improve the environment and security of vulnerable objects.

Displays: Before a strategy based on solution and control can be developed, activities that could affect the displays need to be assessed. These are:

- occupancy, use, functions and loans
- construction work, refurbishment, disaster prevention and maintenance routines

Fig 23 Ranger's House.

Fig 24 Showcases at Ranger's House. The design is based on the showcases originally commissioned by Julius Werhner for his collections.

The objectives of the exhibition at Ranger's House were as follows:

• To give a sense of the opulence of the Red Room in Bath House through the use of original and reproduction display cases.
• To juxtapose contrasting types of objects, as preferred by Sir Julius, instead of being grouped together by date or type, as was customary in museums at the time.
• To use discreet display lighting to enhance the quality of the objects.
• To use a passive method of relative humidity and temperature control within the display cases.
• To be able to cope effectively with coach parties, private views and other functions, such as lectures, parties and dinners linked to the Friends and the Wernher Foundation.

Solution concept: The reference to display cases in these objectives gives a strong indication that the focus of the solution had to be on the appearance and technical performance of the cases. Ambient temperature control would provide comfortable conditions for staff and visitors, while passive RH-control in the cases would provide humidity control for the objects. Both ambient and case lighting would be needed.

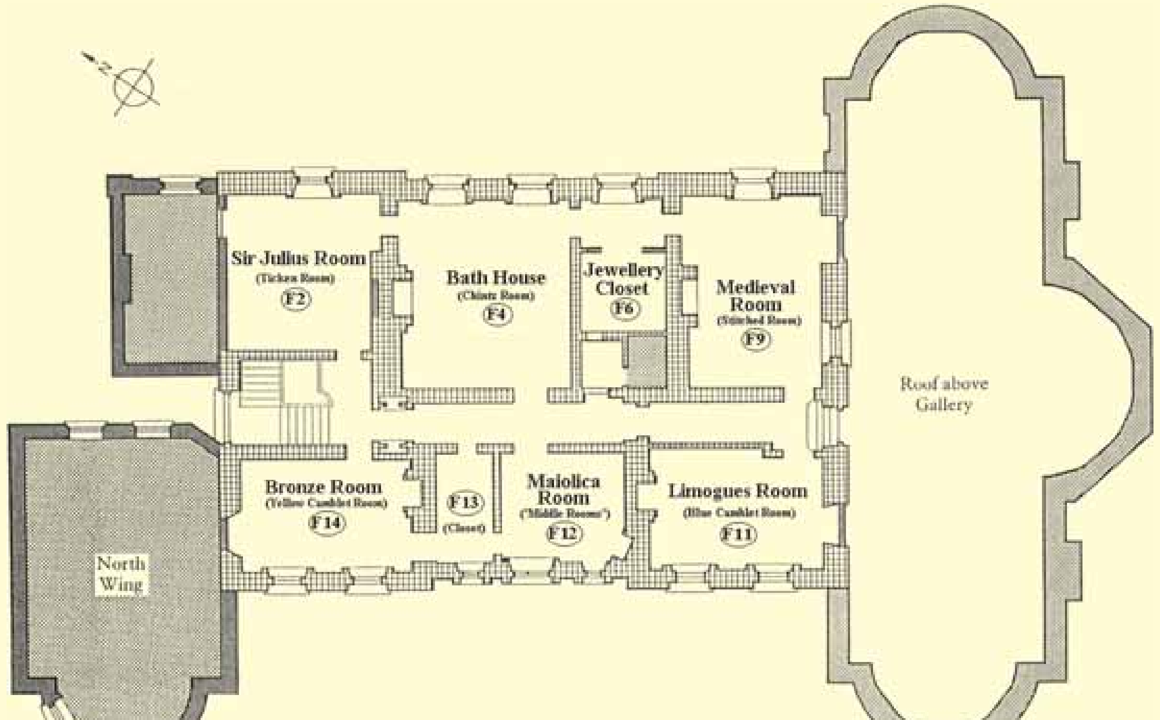


Fig 25 Plan of Ranger's House showing locations of collections.

Control strategy: A sustainable control strategy was developed, based on the following two measures, taken in this order:

1 An understanding of the inherent features of a historic property that promote environmental stability: these are given, and are free. The strategic choice of Ranger's House for the display of The Wernher Collection coupled with the selection of the north-east (or cooler) side of the house for the display of organic objects and the south-west (or warmer) side for the display of inorganic and metallic objects, ensuring that full use was made of the inherent environmental zones of the property.

2 Taking any further actions to enhance passive control would mainly involve capital expenditure. Works were carried out to improve the capability of the house to resist the weather. These included repairs to the roof, chimneys and rainwater goods.

English Heritage produced a specification for the procurement of display cases for the Wernher Collection. The environmental specification included the following requirements:

• that all materials were tested to ensure that there were no corrosive emissions (including the coating of wooden elements to reduce emissions);
• provision of humidity control with silica gel conditioned to certain material-dependant RH bands (ie silica gel cassettes, monitored with a radio-telemetry system);
• pollution control, using activated charcoal cloth;
• and lighting that causes a temperature increase of no more than 5°C per eight hours, using fibre optic cabling and low-voltage tungsten halogen room lamps.

Achieving and maintaining an acceptable solution

Fundamental to good management is good maintenance, and this is important for a historic property that is used as a museum exhibition. A building maintenance programme should ensure that regular inspections take place. This is essential if acceptable conditions are to be achieved and maintained.

Sound environmental management decisions must be based on quantitative, semi-quantitative or qualitative evidence and data, all of which can be useful in environmental management decision-making. Quantitative environmental data and close inspection of exhibits are necessary to determine the early sign of deterioration. English Heritage advisers value effective and clear presentation of environmental monitoring records for diagnostic purposes. This enables anyone unfamiliar with a problem to grasp its significance quickly and to provide the appropriate advice.

Heating and cooling: As in most English Heritage properties, none of the open fires at Ranger's House are lit. This has a number of management and maintenance consequences both for the house and for the museum exhibits:

1 The chimney pots above unused fireplaces should be capped in a manner that enables ventilation of the stack to continue, while avoiding the risks of rain wetting the inside of the stack, damp penetration, disintegration of the flue lining and pest infestation.

2 Chimney flues could be re-used as vertical ducts. They have the potential, with some mechanical assistance, to bring fresh air into the house when external conditions are cooler. This can help alleviate any effects of overheating caused by display lighting and human occupancy.

At Ranger's House, heating is provided by a system of hot-water radiators located under the windows. Heating is managed in an exemplary way with comfort heating to meet the needs of visitors during the day and humidistatic control of heating at night, when the primary function of environmental control is preventive conservation for the collections. The buffering capacity of the display cases effectively protects vulnerable objects from the variations in the operation of the heating system.

Zoning: The environmental differences that naturally occur in different parts of a building can be used deliberately in the environmental management of a property. Managing the environment of a museum exhibition in a historic property can be made easier through diagnostic monitoring showing that the spaces can be mapped as smaller, distinct environmental zones, comprising:

• the 'ambient zone' that staff and visitors occupy;
• the 'microclimates within display cases', which collectively make up the zone occupied by objects;
• and the different faces of the building that correspond to cardinal directions (for example, the north-east face is cooler, while the south-west is warmer at Ranger's House).

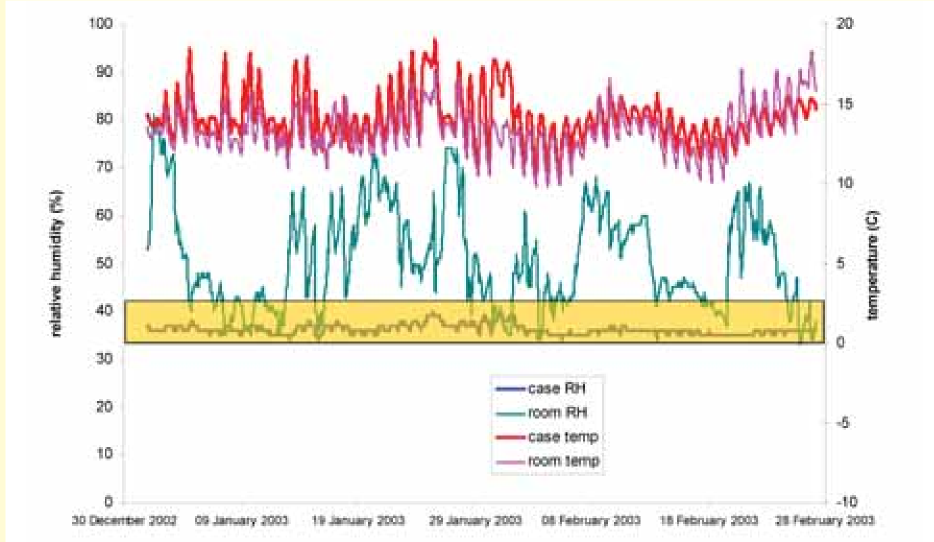


Fig 26 Conditions in a showcase with Limoge Enamels and in the room.

Alarm-based monitoring: Relative humidity and temperature are monitored using a discreet wireless telemetric data-logging system, which is used widely in English Heritage's historic properties. The graph above shows a two-month winter monitoring period of conditions in a room and a case containing Limoges enamels. The yellow box delineates narrow relative humidity control limits of between 35% and 42%. RH has been set low enough to retard alkali migration from the gel layer, and high enough to stop the gel layer from dehydrating and cracking.

Ventilation: Ranger's House had a combination of draughty fireplaces and windows, which were initially sealed to prevent the ingress of dust, pollution and pests. Overheating during the summer, exacerbated by vented display case lighting, meant that the windows had to be unsealed and opened to provide natural ventilation. When openings are closed but not sealed, air infiltration seeped through the cracks and gaps around closed windows and doors as in an ordinary house. During summer Ranger's House could not rely solely on natural air leakage to reduce overheating from a combination of display lighting, occupancy and solar radiation, all of which together had upset the thermal balance within the building. Yet natural ventilation by opening windows is not an acceptable long-term solution because of safety, security and pollution risks, and its adverse affect on the stability of the internal environment.

Future actions to enhance visitor enjoyment of Ranger's House

Mechanically assisted natural ventilation: The fireplaces and chimney flues in Ranger's House have already been compared to vertical ducts. One potential approach is to enhance ventilation, by installing a motorised fan at the top of the chimney to draw fresh air into the rooms. On summer nights when the external air is cooler than daytime temperatures, combined RH/temperature sensors installed inside and outside can switch the fan on to purge the rooms with cooler air. A particle filter can be installed to reduce the ingress of dust, debris and pests, if a heavier-duty fan is feasible. While the feasibility of such a system is investigated, suitable mobile cooling units that can be securely vented externally have been installed.

Points to consider

In summary, the following points or steps were raised as the Ranger's House project was implemented:

1 That naturally occurring zones in buildings can be used to provide environments suited for sensitive objects.

2 That display cases can provide significant environmental protection for their contents, provided that they are carefully designed. Particular care is required for the selection of construction and dressing materials for display cases.

3 That determination of suitable RH conditions for vulnerable objects should ideally be based on relevant published research, specialist evaluation of the condition and stability of the object, and an understanding of the behaviour of water vapour in the air and its interaction with materials (known as psychrometry).

4 That the performance of RH-controlled display cases should always be monitored to assess compliance with the specified conditions and improvements that need to be instigated if the display case fails to perform.

5 That object lighting needs careful specification: in particular, internal lighting of display cases and glare from natural light on the glass can obscure the displays.

6 That the heat gain from large amounts of lighting also needs to be considered. Overheating of cases can seriously affect the environment within them and this problem should be addressed at the design stage.

7 That the positioning of the cases is another important consideration, both within the building, and in particular places within the room (ie avoiding extreme conditions such as direct solar radiation, which can stress the efficacy of cases).

8 That wireless telemetric data-logging systems are ideal for monitoring conditions in cases and rooms within historic properties.

References

Thickett, D, David F and Luxford N 2006 'Air exchange rate; a dominant parameter for showcases'. The Conservator **29**, 19–34

Kerschner, P 1992 'Practical approach to environmental requirements for collections in historic buildings'. J American Instit Conserv **31**, 65–76

Weintraub, S 2002 'Demystifying silica gel'. AIC Objects Speciality Group Postprints **9**, 1–24

Ryan, J L 1995 The Atmospheric Deterioration of Glass. University of London, Imperial College of Science, Technology and Medicine: unpubl PhD dissertation

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Front cover (main photograph): Rangers House, Blackheath, London.
Micrographs from top to bottom:
i boat bedroom, Brodsworth House, near Doncaster;
ii mould infestation in telephone exchange, Dover Secret Wartime Tunnels;
iii Chiswick House, London.

Back cover: Interior Chapel of St Leonard, Farleigh Hungerford Castle, Somerset.

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