

PAS 198:2012

Specification for managing environmental conditions for cultural collections



Collections
Trust



A The National Archives



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Foreword

This Publicly Available Specification (PAS) was sponsored by The National Archives (TNA), with additional sponsorship from Collections Trust, CyMAL: Museums Archives and Libraries Wales, a division of the Welsh Government, and Museums, Libraries and Archives Council. Its development was facilitated by BSI Standards Limited and published under licence from The British Standards Institution. It came into effect on 26 March 2012.

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This PAS is not to be regarded as a British Standard. It will be withdrawn upon publication of its content in, or as, a British Standard.

The PAS process enables a specification to be rapidly developed in order to fulfil an immediate need in industry. A PAS may be considered for further development as a British Standard, or constitute part of the UK input into the development of a European or International Standard.

Relationship with other publications

This PAS can be used in conjunction with the following additional publications for the cultural sector:

- PAS 197:2009, *Code of practice for cultural collections management*

PAS 198 is set within the cultural collections management framework given in PAS 197:2009, in particular with respect to collections care and conservation.

- PD 5454:2012, *Guide for the storage and exhibition of archival materials*

PD 5454:2012 references PAS 198 as a specification for managing environmental conditions for cultural collections that can be used by those managing archives. PD 5454:2012 superseded BS 5454:2000, *Recommendations for the storage and exhibition of archival documents* and PD 0024:2001, *Archival documents – Guide to the interpretation of BS 5454:2000 – Storage and exhibition of archival documents*.

- European standard on sites and buildings intended for the storage and use of cultural collections

The European Committee for Standardization has started work on a new European Standard on sites and buildings intended for the storage and use of cultural collections. The work is being conducted through a working group of the European technical committee, CEN/TC/346, Conservation of cultural property. PAS 198 is expected to form part of the UK's contribution to the environmental aspects of this new European Standard.

Use of this document

It has been assumed in the preparation of this PAS that the execution of its provisions will be entrusted to competent people who are appropriately qualified and experienced in the care and management of cultural collections for whose use it has been produced.

Presentational conventions

The provisions of this standard are presented in roman (i.e. upright) type. Its requirements are expressed in sentences in which the principal auxiliary verb is "shall".

Commentary, explanation and general informative material is presented in italic type, and does not constitute a normative element. The word "should" is used to express recommendations, the word "may" is used to express permissibility and the word "can" is used to express possibility, e.g. a consequence of an action or an event.

Spelling conforms to *The Shorter Oxford English Dictionary*. If a word has more than one spelling, the first spelling in the dictionary is used.

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a PAS cannot confer immunity from legal obligations.

0 Introduction

0.1 General

PAS 198 has been developed to help collecting organizations meet their responsibility to establish and maintain environmental conditions that preserve the cultural collections in their care for future use and enjoyment. It is a specification for managing environmental conditions for collections and covers temperature, relative humidity, light and pollution. The starting point for users of this PAS is to develop an understanding of the sensitivity of collection items to these agents of deterioration.

This PAS aims to help users make their own judgements about specifying beneficial environmental conditions appropriate to local circumstances. The emphasis is on providing conditions for the materials and structures of collection items that will help prevent rapid deterioration or irreversible damage. Although deterioration cannot be arrested altogether, it can be significantly slowed down. Good management of environmental conditions can extend the lifetime of even sensitive materials.

This PAS also takes account of a move in the UK towards energy restraint, prompted by the international drive to reduce the use of fossil fuels. Annex A explains the thinking that underlies the requirements of this PAS on the relationship between energy economy and environmental conditions. Architectural or engineering aspects of environmental control are beyond the scope of this specification, however, and guidance on building options is therefore not included.

0.2 Background

The development of PAS 198 is in part a response to the statement issued by the UK National Museum Directors' Conference (2009) that "museums need to approach long-term collections care in a way that does not require excessive use of energy, whilst recognising their duty of care to collections. There is general agreement that it is time to shift museums' policies for environmental control, loan conditions and the guidance given to architects and engineers from the prescription of close control of ambient conditions throughout buildings and exhibition galleries to a more mutual understanding of the real conservation needs of different categories of object, which have widely

different requirements and may have been exposed to very different environmental conditions in the past."

This PAS also reflects a debate initiated in 2009 by the UK Arts and Humanities Research Council (AHRC) and UK Engineering and Physical Sciences Research Council (EPSRC) Science and Heritage Programme research cluster "Environmental Guidelines: Opportunities and Risks" (EGOR). One of the outcomes of the EGOR initiative was a recommendation that new environmental standards based on recent scientific evidence should be developed for cultural collections in the UK. These should apply to the range of materials commonly found in archives, libraries and museums, thus going beyond the scope of BS 5454:2000, *Recommendations for the storage and exhibition of archival documents*, which has been superseded by PD 5454:2012, *Guide for the storage and exhibition of archival materials*.

0.3 Approach

Users of this PAS are required to evaluate the sensitivity of their collection items to temperature, relative humidity, light and pollution, recognizing that materials react in different ways to different agents of deterioration, and that collection items are often composite objects with a structure combining a number of different materials. Collecting organizations often need to find ways of dealing with a wide range of material sensitivities. Collection items also often have a history of repair and conservation treatments, which can be relevant when specifying beneficial environmental conditions.

This approach reflects the increasing use of the results of research over the past century into the effects of temperature, RH, light exposure and pollution on the rates of change of collection materials, to determine specific environmental conditions for specific aims, rather than highly prescriptive limits for environmental conditions for all collections.

Users are required to make decisions about suitable preservation environments on the basis of information about a collection, including any available data on its current and past storage and display environment, the materials and structures of collection items and their current condition. Other key factors include the significance of particular collection items in the context

of the collection, and the impetus to reduce energy consumption. Decisions need to be made in the context of local priorities, and compromises might be necessary.

On the basis of this information, organizations are required to develop an environmental management strategy appropriate to the collection. The strategy will set out an agreed understanding of the “expected collection lifetime”, that is, the length of time over which the usable life of collection items can be prolonged by means of preservation measures. The expected collection lifetime depends on the resources the organization decides to invest in its collection items for preservation purposes, taking into account their significance, planned use and display, and the rate at which their constituent material or materials would be expected to deteriorate if no preservation measures were taken. The expected collection lifetime could range from a few years for an ephemeral collection to many centuries.

Against the background of the strategy, organizations are required to set an environmental specification for the collection. Guidance on suitable environments is given in Annexes B to G. The aim of these annexes is to help users estimate the likely impact of environmental conditions on the lifetime over which collection items can be preserved, with the focus on those which because of their component materials or complex structure are recognized as sensitive to temperature, relative humidity, light and pollution. Collecting organizations are required to monitor environmental conditions and take measures to mitigate damage caused by these four agents of deterioration.

In implementing this PAS, a balance needs to be struck between the often conflicting demands of the care of the collection, the use and display of collection items and energy economy. While there are many factors that influence the environmental conditions in which collection items are stored, displayed or transported, PAS 198 aims to provide an effective framework for managing the preservation of collections over the expected collection lifetime as the highest priority.

An illustration of the different parameters to consider when setting environmental conditions for a cultural collection is given in Figure 1.

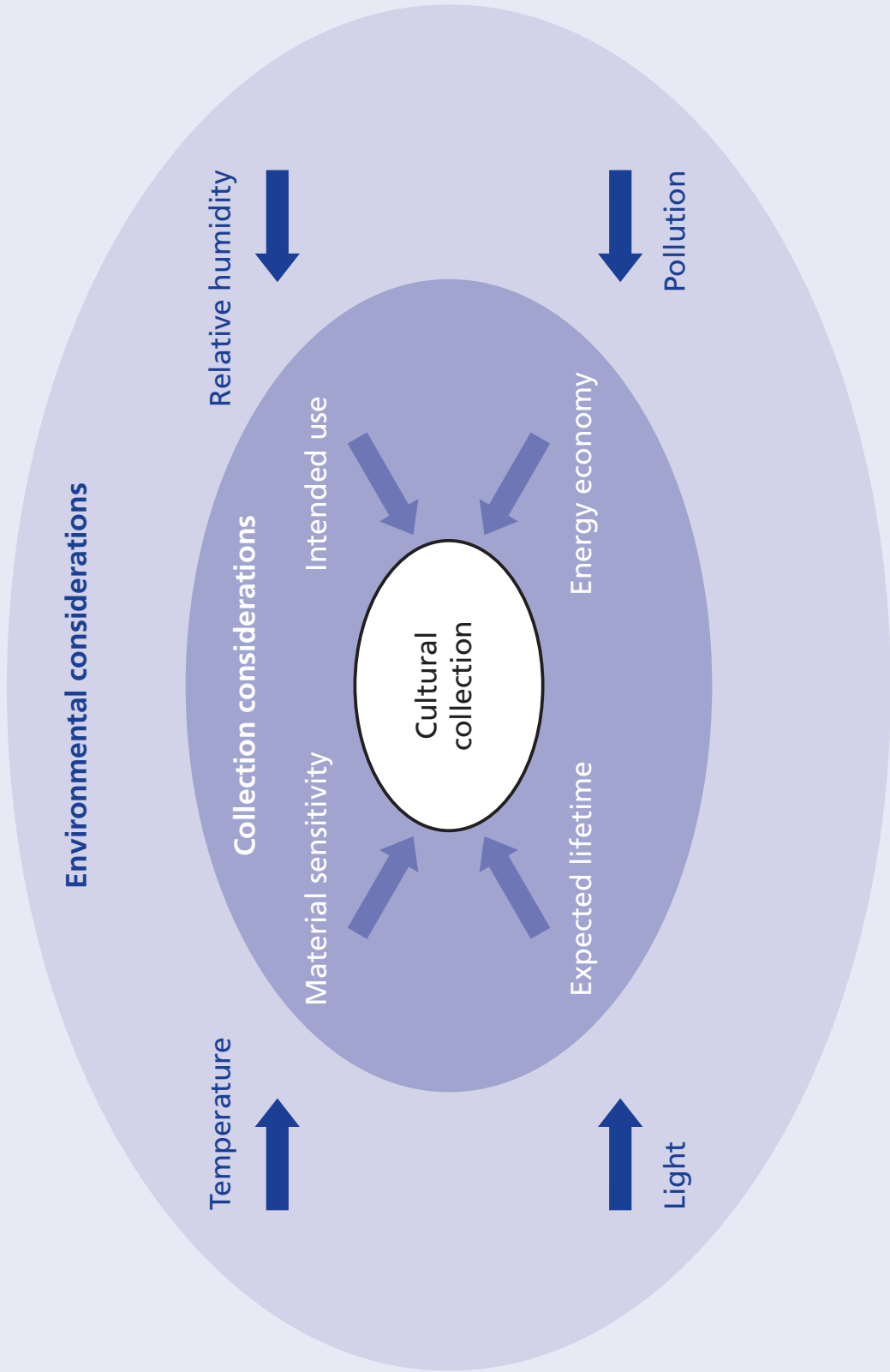
0.4 Research

The body of published research relating to the collection environment has grown over the last 10 years. Where possible, PAS 198 refers to research publications with the aim of promoting understanding of the risks to collections arising from decisions on environmental conditions. Heritage science research is sometimes limited since experimental work cannot be carried out on original objects. As scientific research is therefore often reliant on material models or simulated conditions to measure and predict material change, it might not reflect accurately the behaviour of the actual object being modelled or simulated. Therefore, alongside this empirical research, it continues to be important to take account of the experience of, and data collected by, conservation professionals who witness first-hand the changes to objects over time.

It is recognized that research evidence is lacking in some areas, and where this is the case, accumulated professional experience forms the basis for the requirements. Inclusion of a reference recognizes that it reflects the best available scientific evidence at the time of developing this PAS. In view of the gaps in the evidence currently available, it is clear that further research is needed into the response of a variety of materials commonly found in collections to a broad range of environmental factors and the full range of conditions.

Full details of research publications referenced in this PAS can be found in the bibliography, which has been compiled with contributions from experts including members of the PAS 198 Steering Group and Review Panel and members of TNA PAS 198 Working Group.

Figure 1 – Parameters to consider when setting environmental conditions for a cultural collection



1 Scope

This PAS specifies requirements for managing the setting of environmental conditions for collection items held in cultural collections in the UK, whether in storage, on display or in transit.

It sets out a framework within which environmental conditions can be specified and methods of achieving them can be determined. It also provides guidance in the form of notes and informative annexes to support collecting organizations in complying with the requirements of this PAS. Such informative material, however, does not constitute a normative element of this PAS.

The areas specifically covered by this PAS include:

- a) the general management of environmental conditions (Clause 3, Annex A and Annex B);
- b) temperature (see Clause 4, Annex C and Annex E);
- c) relative humidity (see Clause 5, Annex D and Annex E);
- d) light (see Clause 6 and Annex F); and
- e) pollution (see Clause 7 and Annex G).

This PAS is applicable to all types and sizes of cultural collections held by individual collectors and all types of collecting organizations such as archives, historic houses, libraries and museums, whether public or private.

It covers the materials and physical structures of collection items but does not cover born-digital material.

It does not cover the architectural or engineering aspects of environmental control.

It is for use by collecting organizations with a responsibility for the environmental management of their cultural collections. It can be used by collection owners, collection and building managers, architects and engineers, archivists, conservators, curators, librarians, registrars, scientists and others concerned with collections care and conservation.

It is also of use to sponsoring and funding bodies and others who need to understand the environmental requirements of collections.

It focuses on climatic conditions prevailing in the UK and therefore is aimed primarily at UK users. However, it does take account of an international readership.

2 Terms and definitions

For the purposes of this PAS, the following terms and definitions apply.

NOTE Attention is also drawn to general terms and definitions for the conservation of cultural property given in BS EN 15898.

2.1 agent of deterioration

factor, whether occurring naturally or through human actions, that has the potential to cause harm to a collection item

NOTE For example, temperature, relative humidity, light and pollution.

2.2 anoxic

oxygen-free

2.3 cold storage

storage at temperatures below 0 °C

2.4 collecting organization

organization that collects, cares for and provides access to collection items for education, learning, enjoyment, legal or evidential purposes

NOTE 1 For example, archives, historic houses, libraries or museums.

NOTE 2 Organization includes individuals such as owners of private collections.

[derived from PAS 197:2009, 2.6]

2.5 collection

total body of collection items, or part thereof, held by a collecting organization

[PAS 197:2009, 2.8]

2.6 collection item

object forming part of a collection

NOTE For example, an artefact, book, digital or physical document (including a record), journal, specimen or work of art.

[derived from PAS 197:2009, 2.22]

2.7 collection space

area or enclosure in which collection items are held, all sharing the same body of air

NOTE For example, a building, room, storage cabinet, display case or transit crate.

2.8 collections care

range of activities intended to safeguard a collection

NOTE These activities can include organizational policies, security, storage, cleaning, maintenance, handling, scientific investigation, environmental monitoring and control, exhibitions and loans, conservation, provision of surrogates and emergency planning.

[PAS 197:2009, 2.10]

2.9 collections management

strategies, policies, processes and procedures relating to a collection's development, information, access and care

[PAS 197:2009, 2.14]

2.10 competent person

someone who has the necessary and sufficient training, knowledge, experience, expertise, skills and/or other qualities to complete their allotted task safely and effectively

[PAS 197:2009, 2.16]

2.11 conservation

interventive techniques applied to a collection item to achieve chemical and physical stabilization for the purpose of extending the useful life of the collection item to ensure its continued availability

NOTE Also known as *interventive conservation* and *remedial conservation*.

[derived from PAS 197:2009, 2.17]

2.12 cooled storage

storage at temperatures below the average annual temperature of the location, but not below 0 °C

2.13 cultural collection

collection containing evidence of human activity and the natural environment, accompanied by associated information

[PAS 197:2009, 2.19]

2.14 damage function

quantitative expression of cause and effect relationships between agents of deterioration and material change

2.15 deliquescence

reaction between a solid and atmospheric water vapour causing dissolution to form an aqueous solution on the surface of the solid

2.16 digital ink

ink formulated for use with digital printers

2.17 dust

dry particulate composed mainly of lightweight organic and inorganic materials from a variety of sources

NOTE Chemical and biological sources include buildings, people, traffic and textiles.

2.18 expected collection lifetime

length of time over which the usable life of collection items can be prolonged by means of preservation measures

NOTE The expected collection lifetime depends on the resources an organization decides to invest in its collection items for preservation purposes, taking into account their significance, planned use and display, and the rate at which their constituent material or materials would be expected to deteriorate if no preservation measures were taken.

2.19 general storage

storage of materials at temperatures near the average annual temperature of the location or near human comfort temperatures

2.20 glass transition temperature (T_g)

temperature at which amorphous materials change from hard and brittle to viscous and rubbery

2.21 hydrolysis

chemical reaction in which a compound reacts with water to produce other compounds

2.22 hygroscopic material

material that adsorbs moisture when the environmental relative humidity rises and loses moisture when relative humidity drops

[BS EN 15757:2010, 3.6]

2.23 hypoxic

low-oxygen

2.24 illuminance

quantity of luminous flux falling on a surface

NOTE 1 Also known as light level, light intensity and lux level.

NOTE 2 Illuminance is measured in lux, which is lumen/m².

NOTE 3 A more detailed definition is given in BS ISO 80000-7.

2.25 light exposure

total illuminance over a period of time

NOTE Light exposure is measured in lux-hours.

2.26 luminous flux

amount of light emitted from a light source per second

NOTE 1 Luminous flux is measured in lumens.

NOTE 2 A more detailed definition is given in BS ISO 80000-7.

2.27 thermal response time

time taken to re-establish thermal equilibrium throughout a collection item following a change in ambient temperature

3 General

A collecting organization is expected to determine the environmental conditions for its collection within the context of a documented collections care and conservation policy, recommendations for which are given in PAS 197.

This clause specifies an overall framework for developing an environmental management strategy and setting an environmental specification for a collection. Clauses 4 to 7 specify in detail the approach to be adopted in setting parameters for temperature, relative humidity, light and pollution.

3.1 Assigning responsibility

The organization shall designate competent persons with the responsibility for:

- a) developing and updating an environmental management strategy for the collection in accordance with 3.2;
- b) collecting environmental data relating to the collection in accordance with 3.3;
- c) carrying out an environmental risk assessment in accordance with 3.4;
- d) setting an environmental specification for the collection in accordance with 3.5;
- e) monitoring environmental conditions in accordance with 3.6; and
- f) taking action to mitigate damage and deterioration caused by temperature, relative humidity (RH), light and pollution.

3.2 Developing a strategy

The organization shall develop an environmental management strategy for the collection. The strategy shall include a statement of the expected collection lifetime and the energy demand arising from the environmental conditions needed to achieve this, taking into account the sensitivity, significance and use of individual collection items.

NOTE The strategy should make clear the balance the organization intends to aim for between preservation requirements, usage and display and energy economy.

3.3 Collecting data

The organization shall collect data relating to the collection, including as a minimum data on:

- a) the significance of the collection or collection items therein;

NOTE Conducting a significance assessment should form part of a collecting organization's collections development policy and procedures. Recommendations for conducting a significance assessment are given in PAS 197:2009, 4.3. Attention is also drawn to Russell and Winkworth (2009).

- b) the current and expected usage of collection items, including display, handling, transit and loan;
- c) the condition of the collection;
- d) the past environment of the collection as detailed in any existing records, noting in particular changes over time;
- e) the current external and internal environment of the collection space in order to measure performance over time, including:
 - 1) the temperature and RH inside and outside the collection space in accordance with 4.10 and 5.10;
 - 2) the illuminance or duration of exposure of light falling on collection items in accordance with 6.7;
 - 3) pollutants in accordance with 7.4, any pollution-related damage identified during an inspection conducted at predetermined intervals and, where a problem is identified, the effects of pollutants on collection items;
- f) changes made to environmental control systems; and
- g) energy use, recorded in such a way that energy used for different purposes, for example lighting, heating and ventilation, storage or display, can be measured separately.

3.4 Assessing the risks

The organization shall conduct an environmental risk assessment of collection items, including an assessment of:

- a) the structure and component materials of the collection items, including their history of conservation and repair; and
- b) the sensitivity of the collection items to temperature, RH, light and pollution.

NOTE 1 *The effects of known interactions between one or more agents of deterioration should also be assessed. Examples of known interactions are given in Annex B.*

NOTE 2 *Recommendations for conducting an overall risk assessment of a cultural collection are given in PAS 197. In addition to environmental risks, the overall risk assessment also takes into account risks from other factors such as fire, flood and theft, which are outside the scope of this PAS.*

NOTE 3 *Further guidance on conducting risk assessments is given in BS ISO 31000, Ashley-Smith (1999), Waller (1995) and Waller (2003).*

3.5 Setting an environmental specification

3.5.1 The organization shall set an environmental specification for the collection with the aim of preserving the collection for its expected collection lifetime.

3.5.2 The organization shall set the environmental specification after a review of:

- a) the expected collection lifetime and associated energy demand, as specified in the environmental management strategy in 3.2;
- b) data collected in 3.3; and
- c) the environmental risk assessment conducted in 3.4.

3.5.3 The organization shall include in the environmental specification:

- a) the permissible upper and lower limits, rate of change and fluctuations for temperature (see Clause 4);
- b) the permissible upper and lower limits, rate of change and fluctuations for RH (see Clause 5);
- c) the permissible upper limit for light exposure, upper limit for illuminance and upper limit for UV to light ratio (see Clause 6); and
- d) gaseous pollutants expected to cause unacceptable risk, and any pollution control measures adopted with the intention of enabling the expected collection lifetime to be achieved (see Clause 7).

3.5.4 The organization shall set the environmental specification in 3.5.3 for general storage, cooled storage, cold storage, display and transit.

3.5.5 The organization shall set separate environmental specifications for any microclimates provided for sensitive collection items.

3.5.6 The organization shall conduct a review of environmental conditions at predetermined intervals, taking into account the results of monitoring environmental conditions and inspection of collection items.

NOTE *Further guidance on environmental management is given in ASHRAE (2007), Cassar (1995), Michalski (2007) and Michalski (2009).*

3.6 Monitoring environmental conditions

3.6.1 The organization shall check all monitoring equipment in accordance with the manufacturer's instructions at predetermined intervals to determine that it is fully functional.

3.6.2 The organization shall calibrate all monitoring equipment in accordance with the manufacturer's instructions.

3.6.3 The organization shall conduct a review of the data collected in 3.3 to analyse the environmental conditions of the collection space and identify the need for any improvements.

NOTE *The monitoring of temperature, RH, light and pollution is covered in more detail in 4.10, 5.10, 6.7 and 7.4, respectively. Monitoring should include visual inspection to identify damage and deterioration as well as the use of monitoring equipment.*

3.7 Achieving energy economy

The organization shall include in the environmental specification in 3.5 the measures taken to minimize energy demand.

NOTE *Energy demand can be minimized through, for example, the use of climate and lighting control systems that are highly automated or limited to screening windows and opening doors. Further guidance on energy economy is given in Annex A.*

3.8 Documenting and retaining data

The organization shall document all evidence of having complied with 3.1 to 3.7. The documentation shall be retained in a retrievable form and for a predetermined period of time.

NOTE *Data should be retained in accordance with good practice associated with the formats in which they are kept (for example, paper documents, electronic documents and data sets). Further guidance on records management is given in BS ISO 15489-1.*

4 Temperature

The rates of many deterioration mechanisms (chemical, biological and physical) increase as temperature increases. Changes in temperature within a collection space can also cause deterioration. Given the different dependencies on temperature of these mechanisms, and their differing impact on collection items, a universal temperature range and permissible fluctuations for collections cannot be specified. Attempts to establish a universal safe zone for all collection items by providing conditions required only by sensitive collection items can result in unsafe conditions for atypical collections, as well as leading to unjustifiably increased use of energy.

4.1 Parameters

The environmental specification in 3.5 shall include parameters for temperature that will enable the expected collection lifetime to be achieved, taking into account the materials and structures of collection items and their sensitivity to temperature and changes in temperature. These parameters shall include:

- a) the permissible upper limit for temperature;
- b) the permissible lower limit for temperature;
- c) the permissible rate of change for temperature; and
- d) the permissible fluctuations for temperature.

NOTE 1 A visual representation of the relative risk of damage and deterioration due to temperature is given in Figure C.1 alongside the relative energy demand associated with maintaining a particular temperature.

NOTE 2 More detailed guidance on the material damage and deterioration and risks associated with temperature and RH is given in Annex E for a representative selection of materials found in collections.

NOTE 3 Further temperature and RH requirements for limiting climate-induced mechanical damage in organic hygroscopic materials are given in BS EN 15757.

NOTE 4 Attention is also drawn to Rhyll-Svendsen et al. (2010).

4.2 Upper limit for temperature

The temperature shall not exceed an upper limit that is expected to cause unacceptable irreversible chemical or physical change in collection items, as specified in 3.5.

NOTE 1 Chemical reactions accelerate exponentially as temperature rises. A practical approximation for organic materials is that reaction rates double with each 5 °C rise.

NOTE 2 A temperature on the surface of a collection item exceeding 30 °C can cause permanent distortion, change of gloss or melting. Plastics and waxes are particularly sensitive, others, e.g. resins, adhesives, paints and varnishes, less so. Materials such as acrylic emulsion paints with a glass transition temperature (T_g) near or below room temperature can soften at room temperature. If temperatures exceed 30 °C for long periods of time, slow creep and flow can occur, leading to permanent distortion of these materials. The rate of soiling of these materials also increases in the presence of airborne pollutants.

4.3 Lower limit for temperature

The temperature shall not fall below a lower limit that is expected to cause unacceptable physical damage in collection items, as specified in 3.5.

NOTE 1 The minimum safe temperature for a collection is 5 °C, to avoid the temperature in parts of the building falling below 0 °C with consequent freezing of water pipes and risk of flood damage.

NOTE 2 Very low temperatures are effective in slowing chemical degradation, and should be maintained for some types of highly sensitive materials. However, below –30 °C, hygroscopic materials equilibrated to a moderate RH at room temperature can be damaged by the formation of ice crystals. Some materials embrittle below their T_g thus increasing the risk of other physical damage caused by movement or shock.

4.4 Rate of change of temperature

The temperature shall not change at a rate that is expected to cause unacceptable irreversible chemical or physical change in collection items, as specified in 3.5.

NOTE 1 *If the surface temperature of a collection item changes over a period shorter than its thermal response time, an internal temperature gradient occurs, causing internal stress. Brittle materials (such as ceramics and glass) that have sustained sudden temperature changes can show resulting visible damage. This applies especially to collection items such as mirrors or enamelware, where ceramic or glass is combined with metal or organic layers.*

NOTE 2 *The thermal response time of collection items varies from minutes to hours, depending on thickness and type of constituent materials. If major temperature changes are necessary for operational reasons, such as seasonal energy savings, the period of adjustment should be spread over a period several times longer than the slowest response time of collection items.*

4.5 Linkage of temperature to relative humidity control

4.5.1 Given the linked effects of temperature and RH on the chemical stability of many collection items, a statement shall be documented detailing how the permissible upper limit for temperature has been set in conjunction with the permissible limits for RH specified in 3.5.

NOTE 1 *A useful approximation is that the RH will rise 3% for each degree fall in temperature. However, where temperature and RH are independently controlled by mechanical means or by humidity buffering, there will be no relationship between them.*

NOTE 2 *Since 65% RH is a precautionary limit for mould germination, it can be estimated that there will be a risk of mould in a space usually maintained at x% RH if a drop in temperature reaches $(65 - x)/3$ °C. For example, there can be a risk of mould in a room usually maintained at 50% RH in any part of the room that is 5 °C colder than the average temperature in the main volume of the space.*

NOTE 3 *A useful approximation for a space maintained near 50% RH is that condensation develops on any surface more than 10 °C colder than the temperature at which the RH is 50%. Precise calculations can be made using a standard psychrometric chart.*

NOTE 4 *Further requirements and guidance on setting limits for RH are given in Clause 5, Annex D, Michalski (2000), Michalski (2002) and Michalski (2009).*

4.5.2 Given the variation in RH caused by a variation in temperature within a collection space, the variation in temperature between any part of the collection and the average temperature in the main volume of the collection space shall not be such as to result in unacceptable RH, as specified in 3.5. In particular, the temperature within areas of a collection space shall not be so high as to cause unacceptable physical damage due to low RH, or so low as to result in RH conditions that allow either condensation or mould germination to occur.

NOTE *The usual cause of large temperature variations within a collection space is the location of collection items adjacent to an exterior wall or floor without sufficient space for air circulation, or location close to heaters, air conditioning equipment or air vents, or in direct sunlight.*

4.6 General storage

4.6.1 The temperature for collection items in general storage shall conform to 4.2 to 4.5.

4.6.2 Collection items shall be stored at ambient temperatures only if their chemical stability at those temperatures is acceptable in accordance with 3.5. Any collection items that would deteriorate rapidly at ambient temperatures shall be placed in cooled storage or cold storage.

NOTE 1 *Most materials found in collections are chemically stable and will have an expected lifetime of centuries at room temperatures below 30 °C but many plastics, films and acidic papers have an expected lifetime of only decades at 25 °C.*

NOTE 2 *Some organic materials can have acceptable expected lifetimes at 20 °C, but their expected lifetimes will fall to approximately one-half at 25 °C and one-quarter at 30 °C.*

NOTE 3 *The annual average outdoor temperature in the UK varies from 8.5 °C to 11 °C. Where average outdoor temperatures are below temperatures normally maintained for human comfort, general storage can take advantage of both higher chemical stability and lower energy demand by operating below human comfort temperatures, as long as RH requirements are also met.*

NOTE 4 *While it is preferable to maintain a stable annual average by means of design of the collection space, it is also acceptable to allow slow and gradual seasonal changes in temperature to improve energy economy, as long as the environmental specification of 3.5 is met.*

NOTE 5 To reduce energy demand as well as the risks associated with malfunction, it is preferable to avoid or reduce the use of mechanical systems in general storage, unless these are required to reduce damaging pollution. This can be achieved within the requirements of 4.2 to 4.5 by means of building design or other methods such as use of enclosures.

NOTE 6 Attention is drawn to Padfield et al. (2007).

4.7 Cooled storage and cold storage

The temperature for collection items in cooled storage and cold storage shall conform to 4.2 to 4.5.

NOTE 1 Special precautions are necessary during removal and replacement of collection items in cold storage. Thermal shock can occur. Condensation can occur on and within a collection item and its container as it is moved between spaces at different temperatures.

NOTE 2 Attention is drawn to Padfield (2002).

4.8 Display

The temperature for collection items on display or in use shall conform to 4.2 to 4.5.

NOTE Where collection items are on open display or where the environment inside display cases is expected to be at room temperature, local requirements for human safety and comfort apply.

4.9 Transit

The temperature for collection items in transit shall conform to 4.2 to 4.5.

NOTE 1 In transit, risks can arise from short periods beyond the permitted upper or lower limits of temperature, rapid fluctuations in temperature, or a significant variation in temperature from one side of the collection item to another. Insulated packaging with some thermal mass within the insulation helps to protect collection items from these risks.

NOTE 2 Attention is drawn to Richard, Mecklenburg and Merrill (1991).

4.10 Monitoring

4.10.1 Temperature measurements shall be recorded at least hourly along with the date, time and location of the measurements and retained for reference with the data collected in 3.3.

NOTE 1 The number and distribution of monitoring points depends on the building and any environmental control system in use.

NOTE 2 Where possible, especially when reliable outdoor measurements are not available from other agencies, the outside temperature should be measured in perpetual shade and away from the wall.

NOTE 3 More detailed guidance on procedures and instruments for measuring temperatures of the air and the surfaces of objects is given in BS EN 15758.

NOTE 4 Attention is also drawn to Padfield (2007).

4.10.2 Temperature sensors shall be calibrated in accordance with the manufacturer's instructions, and a record kept of the calibration.

5 Relative humidity

Relative humidity (RH) influences the rate of many deterioration mechanisms: chemical, biological and physical. Changes in RH can also cause deterioration. Given the different dependencies on RH of these mechanisms, and their differing impact on collection items, a universally safe RH range and permissible fluctuations for collections cannot be specified. Attempts to establish a universal safe zone for all collection items by providing conditions required only by sensitive collection items can result in unsafe conditions for atypical collections, as well as leading to unjustifiably increased use of energy.

RH is monitored and measured as an indicator of changes in moisture content, which can be damaging to collection items.

5.1 Parameters

The environmental specification in 3.5 shall include parameters for RH that will enable the expected collection lifetime to be achieved, taking into account the materials and structures of collection items and their sensitivity to RH and changes in RH. These parameters shall include:

- a) the permissible upper limit for RH;
- b) the permissible lower limit for RH;
- c) the permissible rate of change for RH; and
- d) the permissible fluctuations for RH.

NOTE 1 A visual representation of the relative risk of damage and deterioration due to RH is given in Figure D.1 alongside the relative energy demand associated with maintaining a particular temperature.

NOTE 2 More detailed guidance on the material damage and deterioration and risks associated with temperature and RH is given in Annex E for a representative selection of materials found in collections.

NOTE 3 Attention is drawn to temperature and RH requirements for limiting climate-induced mechanical damage in organic hygroscopic materials given in BS EN 15757.

5.2 Upper limit for relative humidity

5.2.1 RH shall not exceed or remain at an upper limit that is expected to cause unacceptable irreversible physical change in collection items composed of hygroscopic organic materials, as specified in 3.5.

NOTE 1 Hygroscopic organic materials include wood, paper, most natural textile fibres, animal glue, gelatine, most photographic media and most paint media. They respond to change in RH with changes in dimensions and mechanical properties. The upper limit in these cases is relative to the RH at which the collection item is equilibrated, for example, for a collection item equilibrated to 20% RH, a rise to 50% RH could be damaging, while 55% RH would be acceptable for a collection item equilibrated at 50% RH.

NOTE 2 The response time of collection items to RH change depends on the materials, but it varies primarily according to thickness and permeability. Thin (around 1 mm) sheets of organic materials fully exposed to the air will respond in minutes, whereas uncoated wooden objects (around 1 cm) or tight paper stacks will take days, and heavily coated or massive wood weeks or months to respond.

NOTE 3 Enclosed storage of collection items slows the response time of a collection item, depending on the air-tightness and buffering capacity of the enclosure.

NOTE 4 Humidity promotes many forms of chemical deterioration, particularly hydrolysis but also oxidation and degradation caused by pollutants. RH should be kept low to reduce the rate of chemical degradation but should not fall below 30% unless this has been specified as acceptable. Lower RH can be beneficial for some materials and is permissible where there is no risk of physical damage.

NOTE 5 At 75% RH and above, the dimensional change due to each 5% rise in RH increases exponentially. See Note 2 to Annex D.

5.2.2 RH shall not exceed or remain at an upper limit at which mould germination is expected to occur, as specified in 3.5.

NOTE 1 Mould germination and rate of growth are dependent on RH, temperature, air movement, time, species of mould and the nutritious quality of the organic substrate. 65% RH (at 20 °C) is a precautionary limit, although at lower temperatures mould will take longer to germinate. To estimate the time taken for visible growth of mould at higher RH, see Ayerst (1969), Michalski (1993) and Sedlbauer and Krus (2003).

NOTE 2 Mould is more likely to develop in the presence of carbohydrates, proteins (such as gelatine and animal glue) and some waxes and synthetic polymers such as poly(vinyl acetate). These are found, for example, on soiled or sized paper and textiles, paintings with traditional linings and any collection items heavily soiled by dust.

5.2.3 Collection items composed of inorganic materials with specific critical RH, such as minerals, archaeological metals, salt-contaminated metals, some types of glass, salt-laden stone and stone which contains clay shall be identified, and RH shall not exceed an upper limit that is expected to cause unacceptable irreversible change in such collection items, as specified in 3.5.

NOTE 1 Where such collection items form part of a mixed collection, it might be necessary to isolate them from the rest of the collection. Enclosures might need to be used for such collection items. Further guidance on enclosures is given in Notes 1 to 3 of 5.6.

NOTE 2 More detailed guidance on the material damage and deterioration and risks associated with temperature and RH is given in Annex E for a representative selection of materials found in collections.

5.3 Lower limit for relative humidity

RH shall not fall below or remain at a lower limit that is expected to cause unacceptable irreversible physical change in collection items, as specified in 3.5.

NOTE 1 Below 30% RH, the risk of physical damage to most organic materials and some inorganic materials increases rapidly. Each 5% drop in RH below 30% causes almost double the dimensional response as a 5% drop when RH is above 30%.

NOTE 2 Most inorganic materials are stable below 25% RH, and for some of these materials low or very low RH is beneficial, e.g. RH below 18% has been recommended for corroded iron, and RH well below 50% for copper alloys where active corrosion has been observed in a collection. Relevant references to support these observations are given in Annex E.

NOTE 3 Some hydrophobic materials, such as wax, may become electrostatically charged at low RH, thus increasing the risk of soiling.

NOTE 4 Notes 1 to 4 of 5.2.1 also apply.

5.4 Rate of change of relative humidity

RH shall not change at a rate that is expected to cause unacceptable irreversible physical change in collection items, as specified in 3.5.

NOTE 1 A rapid change in the RH of a hygroscopic collection item compared with the collection item's response time will cause an internal RH gradient, which can lead to physical damage. A gradient can be reduced by lowering both the rate and the extent of the change.

NOTE 2 Gradients occur primarily within thick, rigid, uncoated uniform materials. In flexible materials, e.g. books bound with paper, gradients can cause a temporary warp. In extreme cases, this can lead to fracturing. In composite objects containing hygroscopic organic materials, damage can depend more on the extent of the change than on the rate of change (except for very slow change as indicated in Note 2 to 5.2.1). It is important therefore to focus on reducing the extent rather than the rate of change.

NOTE 3 Any given change in RH will cause less stress within materials such as wood, paper, animal glue and oil paints if it occurs over several months rather than a few days.

NOTE 4 Notes 1 to 5 of 5.2.1 also apply.

5.5 Linkage of relative humidity to temperature control

Given the linked effects of temperature and RH on the chemical stability of many collection items, a statement shall be documented detailing how the permissible upper limit for RH has been set in conjunction with the permissible limits for temperature specified in 3.5.

NOTE In cooled storage and cold storage, temperature exerts a greater influence on the chemical stability of many materials than RH. RH can therefore be selected according to physical stability and energy demand considerations.

5.6 General storage

The RH for collection items in general storage shall conform to 5.2 to 5.5.

NOTE 1 *The use of well-made display cases can reduce the need to use mechanical systems.*

NOTE 2 *The use of airtight packaging and enclosures can reduce risks from rapid fluctuations in RH. However, packaging and enclosures that concentrate pollutants to unsafe levels should not be used (see 7.1 and 7.3).*

NOTE 3 *The use of anoxic or hypoxic packaging and enclosures can reduce the rate of oxidative damage, including photo-activated oxidation. However, packaging and enclosures that concentrate pollutants to unsafe levels should not be used (see 7.1 and 7.3), and checks should be made to ensure that the stored materials do not change in the enclosed environment.*

5.7 Cooled storage and cold storage

5.7.1 RH for collection items in cooled storage and cold storage shall conform to 5.2 to 5.5.

NOTE *Collection items in cooled storage and cold storage should be stored so that an acceptable level of moisture content is maintained, for example by controlling RH and/or through the use of containers.*

5.7.2 During retrieval to higher temperatures and prior to re-entry to cooled storage or cold storage, collection items shall be kept or placed in airtight containers or purpose-built acclimatization chambers until temperature equilibrium is reached.

NOTE *Acetate-based film should be placed in permeable containers that permit slow diffusion of any internally generated acetic acid (ethanoic acid). Acetate-based film should only be placed in impermeable containers if kept at temperatures below which the rate of internal generation of acetic acid is slowed to a negligible level. To prevent contamination, adsorbers can be added to impermeable containers to remove acetic acid.*

5.8 Display

RH for collection items on display or in use shall conform to 5.2 to 5.5.

5.9 Transit

RH for collection items in transit shall conform to 5.2 to 5.5.

NOTE 1 *In transit, risks can arise from inappropriate RH. Insulated packaging is critical in achieving RH requirements reliably.*

NOTE 2 *Attention is drawn to Richard, Mecklenburg and Merrill (1991).*

5.10 Monitoring

5.10.1 RH measurements shall be recorded at least hourly, along with the temperature at the RH sensor, and the date, time and location of the measurements, and retained for reference with the data collected in 3.3.

NOTE 1 *More detailed guidance on procedures and instruments for measuring temperatures of the air and the surfaces of objects is given in BS EN 15758.*

NOTE 2 *Attention is also drawn to Padfield (2007).*

5.10.2 RH sensors shall be calibrated in accordance with the manufacturer's instructions, and a record kept of the calibration.

6 Light

Lighting is critical to enjoying and enhancing access to collections. However, all sources of light, whether natural or electric, within a collection space can cause extensive and irreversible damage to collection materials. These can undergo chemical changes, for example, inks, dyes and pigments will discolour; or physical changes, for example, mechanical strength can be lost or glossy materials become matt. Organic materials are usually more sensitive than inorganic materials. Some materials, however, are only slightly sensitive to light, and some not at all.

As the wavelength of radiation decreases, the rate of photochemical damage generally increases. Within the spectrum of visible light, damage increases from red to violet, and ultraviolet (UV) radiation is yet more damaging than violet light. Radiant heat from light sources can also cause damage to collections, as it can lead to uneven distribution of heat or moisture within collection items or produce a desiccating environment. Intensive illumination can also lead to accumulation of heat and heat-related stress of collection items.

Light and UV radiation damage is cumulative and proportional to exposure. Damage can be minimized by reducing either the illuminance or the duration of exposure, or both. We generally see things better in brighter light, so the specification of illuminance is always a compromise between preserving the collection item and making it clearly visible.

In this PAS, light is used to mean visible radiation. Many light sources emit UV radiation and infrared (IR) radiation as well as visible radiation and reference will be made to these forms of radiation as distinct from light.

6.1 Parameters

6.1.1 The environmental specification in **3.5** shall include parameters for light that will enable the expected collection lifetime to be achieved, taking into account the materials of collection items and their sensitivity to light, UV radiation and IR radiation. These parameters shall include:

- a) the permissible upper limit for light exposure, taking into account both illuminance and the duration of light exposure;
- b) the permissible upper limit for illuminance; and
- c) the permissible upper limit for the UV to light ratio.

NOTE 1 *Guidance on the sensitivity of materials to light is given in Annex F.*

NOTE 2 *Consideration should be given to providing motion-activated lighting for photo-sensitive collection items and to limiting display of sensitive collection items, for example through rotation of items.*

NOTE 3 *UV radiation is not required for access, so it can be eliminated, or the UV to light ratio reduced if it cannot be eliminated. UV radiation can be minimized in most spaces, even if illuminance cannot be controlled, by using UV-absorbent filters or films.*

NOTE 4 *The need for staff and any visitors to see the collection should be taken into account when setting parameters for light.*

NOTE 5 *Unnecessary exposure to light sources should be minimized.*

6.1.2 Measures taken to optimize the energy efficiency of light systems and identify lower energy light sources by keeping abreast of technological developments shall be documented.

NOTE *In particular, the most efficient balance to be achieved between the use of daylight and electric light should be considered.*

6.1.3 The sensitivity of collection items to light shall be assessed and documented so that an informed decision can be made about light exposure limits for these sensitive collection items, particularly where there is high demand for access.

NOTE 1 *Different specifications might be required for collection items of differing sensitivity.*

NOTE 2 *Attention is drawn to Ashley-Smith, Derbyshire and Pretzel (2002).*

6.1.4 In collection spaces where control of lighting is limited, or determined by other factors such as authenticity in historic house display, light and UV radiation measurements shall be used to guide the selection and placement of collection items so that the preservation aims of the organization can be achieved.

6.2 Upper limit for light exposure

The cumulative light exposure of collection items shall not exceed an upper limit that is expected to cause unacceptable irreversible physical and chemical change in collection items within a specified period of time, as specified in 3.5.

NOTE *When considering a collection with a range of sensitivities, it is usually consistent with 6.1.1 to 6.1.2 to determine light exposure on the basis of the most highly sensitive collection items.*

6.3 Upper limit for illuminance

Illuminance shall not exceed an upper limit that is the minimum acceptable for the visual task and the viewer for which it is intended, taking into account the sensitivity of collection items to light, as specified in 3.5.

NOTE 1 *50 lux is often adopted as the minimum acceptable illuminance that is suitable for the average visitor. This should provide a viewer under the age of 50 with the ability to see moderate detail in a moderately light object during a reasonable period of inspection. 50 lux should not be used as an absolute value, however, if lower illuminance is acceptable for particular displays. Good lighting design should use not only measured lux levels but also a visual assessment, as the balance of lighting and ambience will affect the experience of the visitor.*

NOTE 2 *A higher illuminance is needed for scholarly study and for conservation work on even light-sensitive collection items. Guidance on illumination for detailed work is given in Michalski (1997) and Michalski (2010).*

6.4 Upper limit for the UV to light ratio

The UV to light ratio shall not exceed 75 $\mu\text{W}/\text{lumen}$.

NOTE *Filters are available that eliminate all or virtually all UV radiation.*

6.5 Storage

Light exposure, illuminance and the UV to light ratio limits for collections in general storage, cooled storage and cold storage, shall conform to 6.2 to 6.4 on the basis that visual access is not required except for an identified set of tasks that need to be conducted safely and effectively.

NOTE 1 *Tasks that might be carried out in storage include retrieval, transportation, replacement, pest inspection, inventory control and security inspections. Acceptable illuminance:*

- a) *for retrieval, transportation, replacement, pest inspection and inventory control should be similar to standard office lighting; and*
- b) *for routine security inspections can be estimated as similar to those required for display, e.g. 50 lux to 150 lux.*

NOTE 2 *In order to minimize light exposure, daylight and electric lighting in storage areas should be completely excludable, and should be excluded when tasks are complete.*

6.6 Display

Light exposure, illuminance and the UV to light ratio limits for collections on display, shall conform to 6.2 to 6.4 on the basis that there is a need for effective visual access by visitors and staff.

6.7 Monitoring

6.7.1 Light exposure and illuminance shall be recorded at a predetermined number of times a day over more than one day, both within the collection space and externally. The date, time and location of the measurements shall be recorded and retained for reference with the data collected in 3.3.

NOTE 1 *Where a light logger is used, light measurements should be taken at least every 5 min.*

NOTE 2 *UV radiation measurements should be recorded at least once a year for all light sources and to check the performance of UV filtering film, or whenever a light source is changed if this occurs more frequently.*

6.7.2 Light and UV radiation sensors shall be calibrated in accordance with the manufacturer's instructions, and a record kept of the calibration.