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Information and documentation — Management of the environmental conditions for archive and library collections

Information et documentation — Gestion des conditions environnementales pour les documents d'archive et de bibliothèque

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Contents

Page

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 46, *Information and documentation*, Subcommittee SC 10, *Requirements for document storage and conditions for preservation*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document covers much of the same ground as BSI/PAS 198[46]. The main difference is that BSI/PAS 198 was designed to be applied in British conditions with a temperate climate. Challenges vary in different climatic zones. Nevertheless, there are principles that are generally applicable.

No one set of conditions is appropriate for all collections in all circumstances because environmental specifications are tailored to the needs of a specific collection, the resources of the institution and the context within which it operates, and the local climate. This document sets out a framework for decision making relating to appropriate environmental conditions for cultural collections in the specific climatic zones.

Since archives, libraries and cultural institutions are guardians of the collective memory, their aim is to preserve material in the long term. They also have a duty to do so in a manner that minimizes the impact on the world's resources and climate. Climate change will affect cultural institutions as much as any other institution, if not more, and the use of energy, particularly from non-renewable sources, should be minimized. Wherever possible, passive (non-energy consuming) solutions are preferred, and buildings should be designed with this aim in mind.

First, the extent and composition of the collections, their significance, their current condition, the ways in which they are used, and the desired lifetime should be taken into account. For example, archive and library collections are likely to contain (in addition to bound and unbound paper and parchment and other organic materials, such as Xuan paper and silk, black and white and colour photographic prints and negatives) gramophone records, tapes and films, and, increasingly, diverse electronic media. In addition, the collections can contain all manner of artefacts in various materials. While many of these materials have similar environmental sensitivities, some have specific requirements that need to be taken into account.

The environment in which the collections are stored, used or displayed, and the resulting risks to them should also be understood. On the basis of the information gathered about the collections, regarding the nature and condition of the collections, it is possible to assess the vulnerability to factors such as temperature, relative humidity, light and pollutants, and thus what steps need to be taken to mitigate those risks. These might include the design of, or modifications to buildings, passive measures to control the environment, or improvements to storage and display techniques.

Every collecting institution can and should be able to carry out these steps, no matter how limited their resources, and irrespective of their climate. Knowledge of the collections, and of the risks, is indispensable to proper management and long term survival of the collections.

The consensus amongst conservation professionals regarding environmental parameters for exhibitions and loans is evolving rapidly. References [29], [206] and [236] give additional information on this. Although there is no doubt that a controlled environment is significant in the preservation of collections, provided that the parameters are appropriate to the materials, it is now generally accepted that daily and seasonal variations in temperature and relative humidity will not cause harm to the majority of collections.

This document also provides access to research that led to some of the changes in ISO 11799.

Information and documentation — Management of the environmental conditions for archive and library collections

1 Scope

This document provides information on recent discussions and changes in recommendations and guidance on environmental management within the cultural heritage field. Conservation research on preventive methodologies and passive control provided by specific construction methods and renovations, developments in technology for controlling the environment, and energy and climate change issues are included.

This document is intended for archives and libraries and other institutions with large volumes of collections that are based on paper. Archives and libraries also have collections that include film, magnetic media, leather, and other organic, inorganic or composite materials. These institutions have a unique challenge of extending the lifespan of these materials for access and use in the present and for future generations. The environment plays a key role in extending the lifespan of all of these materials.

This document is intended for use in preservation planning and ongoing environmental management of permanent storage conditions for archives and library collections and applies to all collections being permanently stored for an institution.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at https://www.iso.org/obp

3.1
air change rate
air flow rate to a space, expressed as volume per unit time, divided by the volume of the space in consistent units

Note 1 to entry: Air change rate is often expressed as air changes per hour.

Note 2 to entry: This term is used where there is active ventilation [see also *ventilation rate* (3.40)].

[SOURCE: ISO 16814:2008, 3.5]

3.2
thermal stratification
tendency of heated air to rise and to arrange itself in layers with the warmest air at the top

3.3
collection
holding
type of documents kept in archives and libraries regardless of their physical format

Note 1 to entry: These are mainly books, manuscripts, files, maps, graphic collections and other documents consisting of paper, but also parchment, papyrus, films, photographic materials, audio-visual recordings, magnetic and optical media, as well as bindings and protective material.

Note 2 to entry: Holdings is a term used more often in archival institutions.

3.4
dew point
measure of atmospheric moisture

Note 1 to entry: It is the temperature at which the water vapour in the air becomes saturated and condensation begins.

3.5
document
recorded information or material object which can be treated as a unit in a documentation process

3.6
effectiveness
extent to which planned activities are realized and planned results are achieved

3.7
energy
electricity, fuels, steam, heat, compressed air, and other like media

Note 1 to entry: For the purposes of this document, energy refers to the various forms of energy, including renewable, which can be purchased, stored, treated, used in equipment or in a process, or recovered.

Note 2 to entry: Energy can be defined as the capacity of a system to produce external activity or perform work.

[SOURCE: ISO 50001:2011, 3.5]

3.8
energy economy
careful management of energy resources

Note 1 to entry: This focuses on appropriate minimal consumption of energy within an institution, and incorporates both knowledge of energy performance and specific *energy efficiency* (3.9) of a building and/or mechanical systems.

3.9
energy efficiency
measures that ensure the building and system function in accordance with the design parameters by the efficient use of energy

[SOURCE: ISO 16813:2006, 3.17]

3.10
energy performance
measurable results related to *energy efficiency* (3.9), energy use and energy consumption

Note 1 to entry: In the context of *energy management systems* (3.12), results can be measured against the organization's energy policy, objectives, targets and other energy performance requirements.

[SOURCE: ISO 50001:2011, 3.12]

3.11
environment
surroundings in which an organization operates, including air, water, land, natural resources, flora, fauna, humans and their interrelationships

Note 1 to entry: Surroundings can extend from within an organization to the local, regional and global system.

Note 2 to entry: Surroundings can be described in terms of biodiversity, ecosystems, climate or other characteristics.

[SOURCE: ISO 14001:2015, 3.2.1]

3.12
environmental management system
part of the management system used to manage environmental aspects, fulfil compliance obligations, and address risks and opportunities

[SOURCE: ISO 14001:2015, 3.1.2]

3.13
environmental performance
performance related to the management of environmental aspects

Note 1 to entry: For an *environmental management system* (3.12), results can be measured against the organization's *environmental policy* (3.14), environmental objectives or other criteria, using indicators.

[SOURCE: ISO 14001:2015, 3.4.11]

3.14
environmental policy
intentions and direction of an organization related to environmental performance formally expressed by its top management

[SOURCE: ISO 14001:2015, 3.1.3]

3.15
glass transition
reversible change in an amorphous polymer or in amorphous regions of a partially crystalline polymer from (or to) a viscous or rubbery condition to (or from) a hard and relatively brittle one

[SOURCE: ISO 11357-2:2013, 3.1]

3.16
glass transition temperature
T_g
characteristic value of the temperature range over which the glass transition takes place

Note 1 to entry: The assigned glass transition temperature ($_g$) may vary, depending on the specific property and on the method and conditions selected to measure it.

[SOURCE: ISO 11357-2:2013, 3.2]

3.17
HVAC system
system that provides heating, ventilation or air conditioning for buildings

[SOURCE: ISO 16814:2008, 3.18]

3.18
hydrolyse
chemical decomposition in which a compound is split into other compounds by reacting with water

3.19
indicator
measurable representation of the condition or status of operations, management or conditions

[SOURCE: ISO 14031:2013, 3.15]

3.20
infiltration air
uncontrolled passage of air into a space through leakage paths in the building envelope

[SOURCE: ISO 16814:2008, 3.20]

3.21
insulation
materials that conduct heat poorly and thereby slow down heat loss from an object or space

3.22
long term storage
storage, for a period of undefined length, of material kept for permanent retention

3.23
maintenance
actions of prevention or correction to support long term functionality of repositories and the systems that support them

Note 1 to entry: Corrective action is taken to prevent recurrence whereas preventive action is taken to prevent occurrence.

3.24
management system
set of interrelated or interacting elements of an organization to establish policies and objectives and processes to achieve those objectives

Note 1 to entry: A management system can address a single discipline or several disciplines (e.g. quality, environment, occupational health and safety, energy, financial management).

Note 2 to entry: The system elements include the organization's structure, roles and responsibilities, planning and operation, performance evaluation and improvement.

Note 3 to entry: The scope of a management system can include the whole of the organization, specific and identified functions of the organization, specific and identified sections of the organization, or one or more functions across a group of organizations.

[SOURCE: ISO 14001:2015, 3.1.1]

3.25
mechanical ventilation
ventilation provided by mechanically powered equipment

[SOURCE: ISO 16814:2008, 3.22]

3.26
monitoring
determining the status of a system, a process or an activity

Note 1 to entry: To determine the status, there might be a need to check, supervise or critically observe.

[SOURCE: ISO 14001:2015, 3.4.8]

3.27
natural ventilation
ventilation through leakage paths (infiltration) and intentional openings (ventilation) in the building envelope or room enclosure, which relies on pressure differences without the aid of powered air-moving components

[SOURCE: ISO 16814:2008, 3.24]

3.28
occupied zone
area designed for occupancy that is dependent on the geometry and the use of the room and specified case by case

Note 1 to entry: Usually used only for areas designed for human occupancy and defined as a volume of air that is confined by horizontal and vertical planes. The vertical planes are usually parallel with the walls of the room.

[SOURCE: ISO 16814:2008, 3.28]

3.29
outdoor air
air entering the system, or opening from outdoors before any air treatment

[SOURCE: ISO 16814:2008, 3.31]

3.30
outdoor air intake
opening through which outdoor air is admitted

[SOURCE: ISO 16814:2008, 3.30]

3.31
performance
measurable result

Note 1 to entry: Performance can relate either to quantitative or qualitative findings.

Note 2 to entry: Performance can relate to the management of activities, processes, products (including services), systems or organizations.

[SOURCE: ISO 14001:2015, 3.4.10]

3.32
process
set of interrelated or interacting activities which transforms inputs into outputs

Note 1 to entry: A process can be documented or not.

[SOURCE: ISO 14001:2015, 3.3.5]

3.33
relative humidity
RH
mass of water vapour in the air by volume divided by mass of water vapour by volume at saturation at the same temperature

[SOURCE: ISO 16814:2008, 3.34]

3.34
repository
building or room designed or arranged and used specifically and exclusively for long term storage of archive or library material

3.35
requirement
need or expectation that is stated, generally implied or obligatory

Note 1 to entry: "Generally implied" means that it is custom or common practice for the organization and interested parties that the need or expectation under consideration is implied.

Note 2 to entry: A specified requirement is one that is stated, for example in documented information.

Note 3 to entry: Requirements other than legal requirements become obligatory when the organization decides to comply with them.

[SOURCE: ISO 14001:2015, 3.2.8]

3.36
sub-cool
process of cooling air below its initial dew point temperature to dehumidify via condensation

Note 1 to entry: The condensation dehumidification is followed by a reheat stage to manage temperature and relative humidity.

3.37
sustainability
maintenance of ecosystem components and functions for future generations, to address economic efficiency, social issues and environmental preservation

[SOURCE: ISO 16813:2006, 3.27]

3.38
systems
processes undergoing assessment

Note 1 to entry: Examples include heating, cooling, domestic hot water, lighting, ventilation and relevant automation or control.

[SOURCE: ISO 23045:2008, 3.3]

3.39
ventilation
process of supplying or removing air by natural means or mechanical means to or from a space for the purpose of controlling air contaminant levels, humidity, odours or temperature within the space

[SOURCE: ISO 16814:2008, 3.44]

3.40
ventilation rate
airflow rate at which outdoor air enters a building or enclosed space

[SOURCE: ISO 16814:2008, 3.45]

4 General

To manage the environment in an archive or library, objectives for planning and decisions should be determined. It should be determined what purpose environmental management will serve in meeting the preservation needs of the collections. Environmental management is often the major form of preservation action that can be carried out for all collections to prevent or slow down the deterioration of the most common materials found in archive and library collections. Determining the expected lifespan for the collections will help to determine limits to exposure to high temperature and high relative humidity and the priority within the collections for maintaining the best environment possible. To do this appropriately, the knowledge of the collections and the specific vulnerabilities of materials and formats is vital.

It is advisable to collect data relating to the collections, including:

— the materials present in the collections, and the quantities of each;

— the significance of the items, and the aspects of the items that form the basis of their significance;

— the desired lifetime of the items;

— the present condition of the collections;

— the ways in which the collections are used, including storage, handling, display or loan;

— the history of any conservation or other interventions that might affect the stability or vulnerability.

The quantities need only be approximate, but it is important that all materials present are identified.

The significance of an item is the key to why it is in the collections: it is important to understand what aspect of it gives it its significance, as it is this that should be preserved.

All materials deteriorate slowly even under the best conditions. It is not helpful to say that items should be preserved "in perpetuity", as this implies that infinite resources should be spent on doing so. It may be more useful to speak about the point at which the original significance of the item is lost, or when it has become "unfit for use". It has been suggested[29] that each institution should select a planning horizon that is realistic for their circumstances (possibly 50, 100, 500 years, or longer) and, on the basis of the nature of the collections and the present storage environment, to predict when the item will cease to be fit for purpose. If the point at which the item become unusable comes before the planning horizon, it indicates that there is a choice of doing something about the lifetime or, if resources do not allow action, accepting that this point is the item's lifetime. If the point of non-usability is beyond the planning horizon, it indicates that nothing needs to be changed. If the point of non-usability is somewhere close to the planning horizon, it indicates that nothing needs to be changed in the present because a review at set intervals may involve new information and a new starting point.

The long term planning horizon has been explored recently in a series of papers based on research carried out at the Centre for Sustainable Heritage, University College of London[241]. In this research, surveys of public users of archive and library materials studied what is considered "unfit for use" in terms of the threshold of damage, or extent of physical change that is assessed as damage. This research is significant for the environmental management of collections because the changes considered were discolouration and mechanical deterioration, such as tears and missing pieces, often an indicator of brittle and fragile materials. These physical changes are often seen in archive and library materials that have been maintained in inappropriate environments for long periods of time.

An assessment of the present condition may indicate whether items are stable, at risk or actively deteriorating which may provide information on the suitability or unsuitability of the current environment.

The institution will need to collect data relating to the environments in which collections are stored, handled, displayed or loaned, including:

— records of the internal and external temperature and relative humidity;

— records of the levels of visible and ultraviolet light to which items are exposed, and the duration of such exposure;

— records of gaseous and particulate pollutants to which items are exposed;

— where active methods of environmental control are used, such as mechanical ventilation, filtration, heating, cooling, humidification and dehumidification, records shall be made of the control settings and any alterations made to them (e.g. seasonal variations) and the amount of energy used by each of these systems.

Where possible, records should be made of the conditions in each different environment in which collections are housed.

All environmental monitoring equipment should be maintained and calibrated regularly, in accordance with the manufacturers' recommendations.

All the above records should be kept permanently and shall be reviewed regularly to see whether there are seasonal or longer term trends.

On the basis of the information gathered above, the institution will be able to assess the environmental risks to the collections.

On the basis of the environmental risk assessment, the institution will be able to set an environmental specification for the storage, handling, display and loan of items. As appropriate, this will set the permissible upper and lower limits, rate of change and fluctuations for temperature and relative humidity, the maximum permissible visible and ultraviolet light exposure, and the maximum permissible gaseous and particulate pollutant concentrations.

Where active methods of environmental control are used, the institution should endeavour to minimize the amount of non-renewable energy consumed.

5 Management of environment for optimization of preservation and sustainability

Achieving long term, sustainable preservation of archive and library materials requires that institutions approach the process of preservation with a different mindset than has been common in the past. Because no one set of environmental conditions or building operations is appropriate for all collections in all circumstances, and because it is no longer practical to achieve preservation while disregarding energy costs and consumption of non-renewable resources, it is helpful to approach the topic of sustainable preservation with a goal of optimising preservation with a building's operation. Defined, an optimal preservation environment is one that achieves the best possible preservation for collections at the least possible energy cost, and that is sustainable over time.

Optimization requires a holistic understanding of the collections and the building that contains them. It is not simply about temperature, relative humidity and other environmental factors, but about overall risk management for the collections, an awareness of the challenges or benefits that the local outdoor climate may provide, and knowledge of how the building and any mechanical systems that are designed to temper those outdoor conditions. Documenting and understanding those factors forms three critical questions that should be addressed as institutions manage the change from prescriptive environmental standards to locally determined best practices for preservation and energy usage.

— What is the current preservation environment that is maintained?

— Could it or must it be improved?

— Is more energy used than necessary to achieve that environment?

Like many aspects of collections management, creating and optimizing a sustainable preservation environment is not a onetime project, but rather an ongoing process that should be monitored and maintained over time.

A team of interdisciplinary colleagues, in the form of an environmental management team consisting of individuals from collections management and preservation, facilities management or engineering, and institutional administration, will have the requisite skills and knowledge to shepherd this change. The process requires a leader, often from the collections or facilities staff, to champion the process and oversee the work of the group. The goal is to encourage joint decision making, taking into account the needs of preservation, facilities, and administration on issues that involve collections preservation environments. In order to achieve this level of communication, it is recommended that team members strive to gain a working understanding of their colleagues' responsibilities, meaning that collections staff should learn about the building space and any mechanical systems that create the environment for their collections, while facilities staff should learn more about the institution's collections and their preservation needs.

It may be advisable to refer to the educational and assessment tools (see Clause 15) as a group and/or consult with professional colleagues in similar institutions, consultants in environmental management specifically for cultural institutions and international (i.e. ICOM, IFLA and ICA) and national and academic institutions.

Once the team is formed, optimization is a process that is continuous and includes the following steps:

— documentation;

— data gathering;

— analysis;

— experimentation and implementation;

— assessment and maintenance.

Documentation is the process of creating a shared repository of information about outdoor climate, building characteristics, collections and their preservation needs, and any mechanical systems that may impact the collections environment. Some information will be available through existing documents, while other information, such as mechanical system layout or location of various collections, may need to be discovered as part of the process.

Data gathering is the practice of using data loggers, building management systems, or other sources of temperature, relative humidity, air flows, light or pollution measurements, to provide information about long term environmental trends in collections and other building areas. The goal is to have representative information that will allow for data driven decision making regarding environmental conditions for the preservation of collections materials. Data should be gathered from any space where collections are stored, exhibited, worked on, or otherwise present for any length of time. The length of time for data gathering may vary, but to understand the behaviour of environments in response to changing outdoor conditions, a minimum of one year is recommended. In all circumstances, the longer the data gathering period, the more useful the information will be for assessment and strategic decision making as it provides a way to track environmental conditions and building and mechanical system performance over time.

Where automated monitoring systems are used, these should be capable of indicating any out of specification condition without delay by means of an alarm or similar system. Sophisticated computer-based data monitoring systems may be installed, which can aid with planning of preventive maintenance and can also provide trend logging. Attention should be paid to the placement of the sensors to ensure that the data are representative of the room as a whole. It is unwise to rely solely on a sensor in the return air duct.

The analysis step is the process of examining the available data to identify and assess preservation risks based on conditions of temperature, relative humidity, light, pollution, or other related factors. This analysis may be as simple as comparing recording data to the target ranges of conditions, or may entail more detailed analysis through the use of various tools/metrics (see Clause 15). Beyond identification, another key aspect of the analysis step is to compare levels of risk from various threats to determine where priorities for risk mitigation (lowering relative humidity to reducing mould risk, lowering temperature to reduce rates of chemical decay) lie. In addition, the data analysis, when performed by the environmental management team, may help identify opportunities for more sustainable operation of preservation environments, such as occasions of overheating or humidification of spaces. As the team performs the analysis, the identified risks and opportunities, whether for collections preservation or for energy savings, should be documented. Once documented, the team should assign priority for addressing the risks or opportunities.

Experimentation with, and implementation of, new environmental conditions or building or mechanical system operational settings allows the team to test and identify new strategies that may be used for either preservation benefit, energy savings without negatively impacting preservation quality, or both. Proposed changes in management and approach should be tested, normally for periods of two to four weeks, and conducted in multiple seasons if necessary. The team should continue data gathering for the affected space throughout the test period, then analyse the data to assess whether the adjustment successfully addressed the documented risk or opportunity, what the overall impact on the preservation environment was, and whether the tested strategy will remain as part of the normal building/system/environment operation.

Once the team has tested and adopted any strategies for optimizing the performance of the preservation environment, the process enters the assessment and maintenance phase. As data gathering in the space continues, the team can use the environmental data, combined with any tools or metrics, to assess and quantify the impact of the changes on the overall preservation quality of the space, or to quantify the impact of any energy optimization measures on sustainability or energy expenditure goals. This quantification is a check against whether strategies are performing as expected, but also serves as a valuable communication tool for institutional administration and other colleagues. The ongoing assessment should include periodic reviews of data, strategies, and operational guidelines, to ensure that the collections environment, building, and any mechanical systems are still performing as defined by the team. When changes or anomalies are discovered, the team can repeat steps of the optimization work process as needed to propose and identify the appropriate corrections to the collections environment. As the team reaches the maintenance stage of the process, it can work at developing appropriate institution specific procedures for the ongoing process, with the goal of integrating the optimization process into normal institutional procedures and workflow.

Much of this process is outlined more specifically in the Reference [91].

6 Temperature

The environmental specification shall include parameters for temperature that will enable the expected collections lifetime to be achieved, taking into account the materials and structures of collections 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;

d) the permissible fluctuations for temperature, including the time scale (daily, weekly, and seasonally);

e) the specification of a target or target range.

NOTE 1 The temperature set points depend upon the dew point control in the space and the relative humidity parameters specified. See Clause 13.

NOTE 2 Items c) and d) have been the subject of research and the findings indicate that rates of change and fluctuations are less significant for archive and library collections than indicated in previous standards[130].

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 collections, a universal temperature range and permissible fluctuations for collections cannot be specified.

Attempts to establish a universal safe zone for all collections by providing conditions required only by sensitive collections items can result in harmful conditions for other collections, as well as leading to unjustifiably increased use of energy. Where only small numbers of sensitive items are present in an otherwise less sensitive holding, it is simpler and more cost effective to store them in a refrigerator, freezer or cold store as appropriate.

Chemical reactions accelerate exponentially as temperature rises. Different materials have different sensitivities to temperature changes (see Annex A), but a practical approximation for organic materials is that reaction rates double with each 5 °C rise. Note that although reducing the temperature or the relative humidity individually will reduce the rate of deterioration of materials, reducing both together will have a dramatically greater effect.

One simple environmental approach for many collections is to maintain a temperature as cool as possible, with moderate relative humidity of 30 % to 55 %. However, risk to specific materials can vary significantly.

Many materials found in collections will have an expected lifetime of centuries at room temperatures but some plastics, such as cellulose acetate, and acidic papers have an expected lifetime of only decades at 25 °C. 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.

Apart from these slow and continuous deterioration mechanisms, a few materials are affected directly by high or low temperatures. For example, a temperature on the surface of some materials exceeding 30 °C can cause permanent distortion, change of gloss or melting.

NOTE 3 Materials such as polyethylene and beeswax 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.

Likewise, very low temperatures are effective in slowing chemical degradation, and should be maintained for some types of highly sensitive materials.

NOTE 4 Some materials embrittle below their T_g thus increasing the risk of other physical damage caused by movement or shock (e.g. photographic film, deteriorated leather).

Although many materials are comparatively impervious to high or low temperatures, temperature changes are linked to changes in relative humidity unless the environment is actively controlled. These changes in relative humidity are likely to be more damaging than the temperature changes themselves (see Clause 7). A useful approximation is that the relative humidity will rise by 3 % for each degree Celsius (°C) fall in temperature, and vice versa.

In addition to the effects of high or low temperatures, some materials may be damaged by sudden temperature changes. For example, if the surface temperature of an item changes over a period shorter than its thermal response time, an internal temperature gradient occurs, causing internal stress. The thermal response time of items varies from minutes to hours, depending on thickness and type of constituent materials. Sudden major temperature changes may occur if, for example, direct sunlight falls on an object or a display case, or when display lighting is switched on or off. Instead, the period of adjustment should be spread over a period several times longer than the slowest response time of the items. The operation of heating and cooling controls should be checked to ensure that large or rapidly fluctuating temperature changes do not occur.

NOTE 5 A visual representation of the relative risk of damage and deterioration due to temperature is given in Annex B alongside the relative energy demand associated with maintaining a particular temperature.

NOTE 6 A more detailed guidance on the material damage and deterioration and risks associated with temperature and RH is given in Annex C for a representative selection of materials found in collections.

NOTE 7 Further temperature and RH requirements for limiting climate induced mechanical damage in organic hygroscopic materials are given in EN 15757[18].

7 Relative humidity

The environmental specification shall include parameters for relative humidity (RH) that will enable the expected collections 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;

d) the permissible fluctuations for RH, including the time scale (daily, weekly, seasonally) daily, weekly, seasonally);

e) specification of a target or target range.

NOTE 1 Remember that the relative humidity parameters will depend upon the dew point control in the space and the temperature set points specified. See Clause 13.

NOTE 2 Items c) and d) have been the subject of research and the findings indicate that rates of change and fluctuations are less significant for archive and library collections than indicated in previous standards[130].

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 collections items, a universally safe RH range and permissible fluctuations for collections cannot be specified. Attempts to establish a universal safe zone for all collections items by providing conditions required only by sensitive collections items can result in harmful conditions for other collections, as well as leading to unjustifiably increased use of energy. Where only small numbers of sensitive items are present in an otherwise less sensitive holding, it is simpler and more cost effective to package them individually or together in a microenvironment with a controlled relative humidity, or where larger numbers are concerned, in a climate controlled cabinet or separate store room.

Archive and library collections contain many hygroscopic organic materials, which absorb water vapour when the RH is high, and lose it when the RH falls. These changes in moisture content are accompanied by dimensional changes which can cause physical damage to items (e.g. splitting, cockling, and loss of pigment from surfaces). Inorganic materials are not usually hygroscopic and are dimensionally stable, but some (e.g. metals, certain types of glass) may corrode under conditions of high RH.

Hygroscopic organic materials include wood, paper, most natural textile fibres, parchment, leather, 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 item is equilibrated, for example, for an item equilibrated to 20 % RH, a rise to 50 % RH could be damaging, while 55 % RH would be acceptable for an item equilibrated at 50 % RH.

The response time of an item to RH change depends on the materials, but varies primarily according to thickness, permeability, and surface exposure. Thin (up to about 1 mm thick) sheets of organic materials fully exposed to the air will respond in minutes, whereas uncoated wooden objects (1 cm or more thick) or tight paper stacks will take days, and heavily coated or massive wood weeks or months to fully respond.

Storage of items in enclosures may slow down the response time, depending on the airtightness and buffering capacity of the enclosure.

Although hygroscopic materials will buffer their own environment to some extent depending on the size of the enclosure and the quantity of material, sensitive materials such as metals should never be sealed in an impermeable container without a buffer to control the RH.

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. Acclimatization will be necessary if items equilibrated to a low relative humidity are brought into an area of higher relative humidity, and vice versa.

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

A visual representation of the relative risk of damage and deterioration due to RH is given in Annex C alongside the relative energy demand associated with maintaining a particular temperature. Note that although reducing the relative humidity or the temperature individually will reduce the rate of deterioration of materials, reducing both together will have a dramatically greater effect.

More detailed guidance on the material damage and deterioration and risks associated with temperature and RH is given in Annex D for a representative selection of materials found in collections. Attention is drawn to temperature and RH requirements for limiting climate induced mechanical damage in organic hygroscopic materials given in EN 15757[18].

In addition to chemical deterioration caused by hydrolysis and oxidation, and physical damage caused by expansion and contraction, organic materials are also subject to biological damage caused by moulds and bacteria. 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.

NOTE 3 To estimate the time taken for visible growth of mould at higher RH, see References [35], [141] and [199].

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 polyvinyl acetate. These are found, for example, on soiled or sized paper and textiles and any collections items heavily soiled by dust.

8 Climate and its consequences for collections

8.1 General

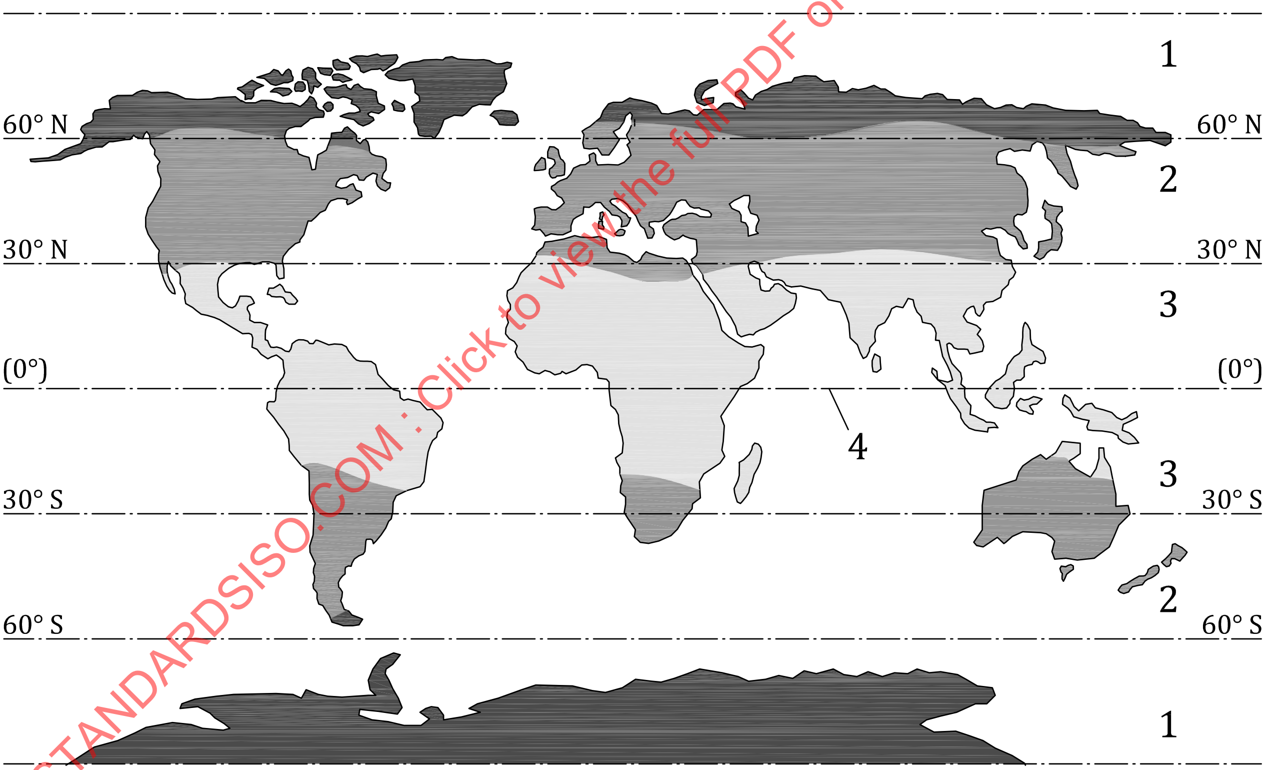


Figure 1 — Climate map

The different climates of the world can be classified in many different ways, such as the Köppen-Geiger classification, but for simplicity, they can be classified into four categories: cool and dry, cool and humid, warm and dry and warm and humid.

This is an oversimplification, but it is adequate for the purposes of this document. Local climate may be profoundly affected by factors such as proximity to large bodies of water (lakes, seas) and by elevation. The effects of climate change are still not entirely clear, but it may be anticipated that extreme weather events will become more frequent and that maximum temperatures will increase. These factors should be taken into account during the preservation planning. The risks to collections will vary in these different zones, and human responses to them will likewise be different. In all cases, the aim of building design is to stabilize the internal climate by isolating it as far as possible from external changes. Traditionally, this has been achieved by massive construction, which is expensive, although lightweight insulation can be equally efficient and more cost effective. In temperate climate zones, the internal conditions may be acceptable for much of the year, only requiring mechanical intervention in the depths of winter or the height of summer.

a) Cool and dry (mean winter temperature of less than 4 °C, mean RH less than 40 %)

EXAMPLES Northern parts of North America, Central Asia.

In principle, low temperatures and low RH are favourable to the preservation of most materials. The rates of chemical reactions (e.g. corrosion, hydrolysis) are reduced and biological agents (e.g. insect pests, fungi) are inhibited. Storage areas with no or little human presence may not require heating or humidification.

For human comfort, heating in winter is generally required and, given the low ambient RH, this will cause dangerously low RH for hygroscopic organic materials. Areas where collections are used (e.g. displays, reading rooms) will therefore need to be humidified, which implies the capital cost of equipment and the energy cost of running it. There are also consequences for the design of the building: water vapour will migrate towards the outside, and unless there is an efficient vapour barrier condensation or even freezing will occur in the external walls, probably leading to severe structural damage. On the other hand, items will need to be acclimatized if they are brought into the warm humidified areas from unheated storage rooms, and likewise on their return to storage.

b) Cool and humid (mean winter temperature of less than 4 °C, mean RH more than 60 %)

EXAMPLES Northern and Central Europe, much of North America.

The major hazard in this climate is the growth of mould.

Winter heating for human comfort will still be required in these climates, and the RH in heated areas will still be too low unless humidification is used. Unheated storage areas will be too damp: they will either need dehumidification or humidistat-controlled heating (conservation heating) to obtain an acceptable level of RH in order to reduce the risks of corrosion of metals or mould growth on organic materials. In either case, there will be capital and energy costs to consider.

c) Warm and dry (mean annual temperature more than 18 °C, mean RH less than 40 %)

EXAMPLES North Africa, much of the Middle East, much of Australia.

Design of the building to exploit passive methods such as isolating the storage areas from the climate, cooling winds, natural shade, massive construction, and efficient insulation may reduce or eliminate the need for mechanical cooling. Although high temperatures will increase the rate of deterioration of materials, the low RH will tend to counter this. If collections areas are mechanically cooled there may also be a need for dehumidification, again leading to higher capital and running costs. Mechanical cooling and possibly humidification may be necessary for human comfort.

d) Warm and humid (mean annual temperature more than 18 °C, mean RH more than 60 %)

EXAMPLES Caribbean, Southeast Asia, the Amazon.

High temperatures and high RH combine to increase the rate of deterioration of most materials. Design of the building to exploit passive methods such as isolating the storage areas from the climate, cooling winds, natural shade, massive construction and efficient insulation may reduce or eliminate the need for mechanical cooling. Preservation of the collections may require some form of mechanical cooling and dehumidification. There will be a risk of corrosion of metals and mould growth on organic objects, which may be mitigated by exploiting natural ventilation to eliminate areas of stagnant air. Mechanical cooling and possibly dehumidification may be necessary for human comfort.

8.2 Seasonal climates

Outside of tropical regions, where the temperature and relative humidity tend to be fairly uniform throughout the year, there will be seasonal variations in the climate, so that there will be a warm season, a dry season, etc. These natural variations mean that the external conditions may be more appropriate for collections preservation at some times of year than others, so that energy-consuming modification of the internal climate may be less necessary.

9 Insects and other pests

Insects and other pests can cause major losses in archive and library collections. If undetected, an infestation of pests (for example, silverfish, or termites) can cause significant damage to the collections. Chemical treatments to control infestation can also be very damaging to the collections. The most important aim should be to avoid, block or control insects and other pests at the point where they enter, such as at the level of the building floor, walls, roof and any openings to the outside. Good collections management practices and a program of Integrated Pest Management (IPM) are important in controlling and monitoring for insects and other pests. See EN 16790[19].

First, it is important to understand the insect and other pests that are a part of the ecosystem in which the institution is located. The country, region and location (e.g. near a body of water, surrounded by a forest, etc.) will determine the vulnerability of the collections to the particular insects and other pests that are part of the surrounding ecosystem. Climate change and movement of goods is a factor causing insects and other pests to be found outside the expected area, so monitoring and identification of the pests found is important for archives and libraries.

Second, analyse the construction and maintenance of the building and identify entry points into the structure (such as seals on door or window frames, holes drilled for electrical and telecommunications wires, cracks in roofs or walls, ductwork for air circulation, etc.). A regular inspection of the building is needed as materials break down, and natural stressors, such as storms can cause new openings.

Third, environmental management impacts the effectiveness of an integrated pest management (IPM) program. Environmental controls can discourage pests from living and flourishing in a space and from being drawn into the space. The environmental factors that can be controlled include cleanliness, temperature, relative humidity, ventilation and lighting. The environmental controls should aim to maintain an environment that is not hospitable to insects and other pests. For example, there are insect pests that prefer higher humidity (e.g. silverfish) and some insects do not nest when there is air circulation. A good filtration of the air being circulated can help to remove particulates that are food and nesting sites for insects.

10 Pollution

High levels of air pollution may accelerate degradation of archival and library material especially if objects are exposed to different pollutants over prolonged periods of time. Published data on local outdoor pollutant concentrations should be examined to determine if there is a need to monitor indoor concentrations.

Particulates (dust) are very small-diameter solid or liquid particles in the air which can penetrate every building. Particulates that come from natural sources such as volcanic eruptions, forest and grassland fires, sea spray and dust storms are usually coarse (particles exceeding 2,5 micrometers in aerodynamic diameter). Manmade sources, such as the burning of fossil fuels in vehicles, agricultural field burning and various industrial processes generate significant amounts of fine particles (aerodynamic diameter smaller than 2,5 micrometres). Particulates can also be produced inside the building (debris from building materials, deteriorating materials, biological sources or human activity).

Organic dust from biological sources provides a source of nutrients for insects, moulds and bacteria. It also may contain active mould spores. Particulates (dust) can cause surface mechanical abrasion which may affect especially magnetic material, and other audiovisual documents, metal, wax and other materials with abrasion sensitive surfaces. Dust may sink into the surface of materials that have glass transition temperatures (T_g) close to room temperature (e.g. beeswax seals, polyethylene film) and become impossible to remove.

Particle deposition may accelerate cellulose degradation and metal corrosion. The deposit of hygroscopic, oily, or metallic particles on a surface can initiate or accelerate deterioration, as well as the formation of harmful compounds such as acids[147].

The damage to collections caused by airborne gaseous pollutants is cumulative, irreversible and not immediately visible. Gaseous pollutants are both externally and internally generated. Common outside sources are automotive exhaust and industrial processes. Pollutants also can be produced within the storage area in the process of deterioration of archival material or poor-quality enclosures and boxes. Materials used to fabricate enclosures, storage and display cases or furniture shall be evaluated to determine that they do not emit gaseous pollutants that may cause irreversible change of archival or library material. Pollutants released by degrading material may affect adjacent materials in the same enclosure or storage area. Activities such as photocopying, general maintenance, or building construction can introduce ozone, formaldehyde, ammonia, and other pollutants.

NOTE For information on packaging enclosures and materials, see ISO/TR 19814[3].

Gaseous pollutants of concern include the following.

— Sulfur dioxide (SO_2) — sulfur dioxide can react with water and hydrolyses to H_2SO_4 (sulphuric acid), H_2SO_3 (sulphurous acid). Both high-relative humidity and light may instigate or accelerate the reaction of sulfur dioxide with paper, which will cause yellowing and embrittlement. H_2SO_4 depolymerises the cellulosic structure and weakens the collections material. H_2SO_3 fades the colour of inks. collections with paper, leather, fur, textiles, most metals and photographs are sensitive to sulfur acids.

— Nitrogen oxides (NO_x) — NO_x may react with water and be transformed into nitrous and nitric acid. Collections including paper, leather, fur, textiles, most metals and photographs are sensitive to nitrous and nitric acids.

— Ozone (O_3) — Ozone is oxidising pollutant damaging to organic materials. Ozone may reduce the mechanical properties of paper and other organic substrates as well as some synthetic materials. It can cause fading of pigments and organic dyes. Ozone may accelerate the reaction of sulfur dioxide to form sulphuric acid.

— Reduced sulfur compounds — Some materials are susceptible to reduced sulfur compounds such as hydrogen sulphide (H_2S), carbonyl sulphide (COS) even at low levels. Hydrogen sulphide (H_2S) reacts readily with silver to form dark Ag_2S, which damages photographic negatives and daguerreotypes.

— Formaldehyde — Materials that contain urea formaldehyde resins, such as paint, carpeting, printing ink and wood products such as chipboard and medium density fibre board (MDF) may be a source of formaldehyde. It may react with unexposed photographic films, photographs, textiles, lead, and glass; change the structure of materials or reduce their mechanical properties.

— Organic acids — Organic acids can damage most collections' materials. Acetic acid reduces the mechanical properties of paper, and other organic substrates as well as some synthetic materials. Most commonly free acetic acid is produced during deterioration of acetate films and tapes and may accelerate degradation of materials. Woods and papers also are the important source of organic acids.

— Naphthalene, p-dichlorobenzene (PDCB) and pentachlorophenol — Naphthalene was once the primary ingredient in mothballs which were used to protect collections from insect and pests. PDCB was used to control moulds, mildew and sublimes readily near room temperature. Naphthalene, PDCB and pentachlorophenol are harmful to human health.

11 Light

Light causes changes to many archive and library collections depending on the light source, proximity to collections, duration of exposure, and vulnerability of the material that is exposed. Exposure to light may result in chemical changes (e.g. the fading of inks) or physical changes (e.g. the loss of mechanical strength). While some materials are minimally sensitive to light, most archival and library materials are sensitive to light exposure; organic materials are more vulnerable to than inorganic materials.

Sensitivity to light may conveniently be assessed by referring to ISO 105-B08. High sensitivity materials (corresponding to blue wool standards #1, #2 or #3[239]) may show noticeable fading after only a few days exposure to sunlight, while medium sensitivity materials (corresponding to blue wool standards #4, #5 or #6[239]) may show noticeable fading after a few weeks. High sensitivity materials include wood pulp papers containing lignin (such as newsprint), ballpoint and felt-tip pen inks, colour photographs and watercolour pigments. Medium sensitivity materials include iron gall ink, lignin-free paper and parchment. See BSI/PAS 198:2012, Tables F.1 and F.2[46].

There is no simple recommendation for defining safe light levels. Preventive strategies that block, reduce or control light exposure, intensity and duration of exposure to the minimum level necessary, provide the best protection against the damaging effects of light. Storage of archive and library collections in boxes or cases provides protection from many sources of light.

Adequate lighting is needed to manage the collections, including safety in transporting collections, however, if staff is not present, there is no need for lighting storage areas beyond what is required for emergency purposes.

NOTE 1 Radiation from a light source is generally divided into three categories: Ultraviolet (UV) (wavelength shorter than 400 nm), visible light (wavelengths between 400 nm and 760 nm), and Infrared (IR) (wavelengths longer than 760 nm).

The quantity of light falling upon the surface of material is measured in lux or foot candles. One lux equals one lumen per square metre. One foot candle is equivalent to approximately 11 lux. A young person needs a minimum of 50 lux to see an item reasonably clearly, while an older person may need considerably more. Dark coloured objects, or those with fine detail, will also need greater illumination. See Reference [146].

All wavelengths of light, including those in the visible range of the spectrum, can cause damage to sensitive materials. It is advisable to measure and control the total amount of light exposure, while avoiding UV radiation exposure is the most critical.

The UV portion of the light spectrum will transmit more energy than the visible or IR portion and therefore may cause significantly more harm to collections. Films that filter UV from natural and light sources in locations where collections are exhibited, used and stored are often used to protect them.

NOTE 2 As the wavelength of radiation increases, the associated energy decreases, as does the rate of photochemical damage that it can cause. While typically less of a threat than UV radiation, wavelengths in the IR portion of the spectrum cause heating.

Radiant heat is significant from an environmental management perspective. Radiant heat will result in adding heat to the environment, and if not controlled will increase the temperature. Increased temperature, particularly if in an enclosed space, such as an exhibition case can result in over-drying or uneven distribution of heat or moisture content within an item.

Light exposure and heat can be controlled by:

— maintaining the minimum level of lighting needed for tasks, visitor experience and building safety;

— keeping storage areas unlit when not in use with user-activated or timed lighting;

— limiting the number of lights controlled by a single switch to avoid lighting more than the area needed for work;

— measuring and monitoring to ensure that the lighting is not heating the collections;

— eliminating UV radiation through lamp selection, filters in lighting fixtures or case glazing or sources of natural light;

— keeping collections stored in individual boxes, cases, or under covers.

NOTE 3 LED lights generally do not emit UV radiation and generate less radiant heat than other light sources. Fluorescent tubes and bulbs emit varying proportions of UV radiation expressed in microwatts per lumen. Filters are retained when tubes are changed and can lose efficacy over time.

NOTE 4 High efficiency lighting reduces energy and maintenance costs in addition to reducing the need for maintenance work in collection and display areas.

12 Setting a temperature and relative humidity specification

Setting a temperature and relative humidity specification for a storage environment is a critical component of managing preservation and sustainability. While past standards and guidelines have provided specific conditions and limits, research in materials science, increased understanding of interior environments and how they relate to climatic conditions, improvements in building technology and mechanical systems, and increased pressure to achieve energy efficiency and overall sustainability in environmental operation, have contributed to rethinking the approach to setting temperature and relative humidity specifications for archive or library institutions. As materials research has helped to define vulnerabilities and conditions where damage may occur, the key has become the management of environments to minimize these risks while at the same time capitalising on opportunities to improve preservation and reduce energy consumption.

Guidelines in this clause are presented with the goal of achieving a balance between quality, risk-managed preservation environments and reduced energy consumption based on unique institutional factors. Temperate and relative humidity specifications for preservation environments should be determined by an environmental management team, using expertise from many disciplines to address collections needs, building and system capabilities, and institutional needs and priorities.

Broadly, there are six key factors which directly impact the final selection of temperature and relative humidity specifications for an individual storage environment:

— the collections type and its preservation needs;

— the outdoor climate;

— the nature of the building/structure where the collection is stored;

— the availability (or lack thereof) of mechanical systems to mitigate the outdoor climate;

— whether the storage environment is considered an “occupied” or “unoccupied” space;

— and the degree to which the institution prioritizes preservation and energy usage.

It is important to note that, once all six factors are taken into account, it is likely that institutions or buildings that appear similar on the surface may choose very different specifications based on their particular situation. Institutions that have mechanical control of environments may have a broader range of specification flexibility, while institutions that are working in passive or non-mechanized environments may have fewer operational choices, or may be choosing among various physical locations or buildings with different passive conditions, rather than selecting a controlled specification.

Not all materials react to environmental conditions in the same manner. As discussed in Clauses 5 and 6, these factors drive the majority of materials degradation processes, be it chemical decay, mechanical shape change, the presence of pests, mould, or biological decay, or oxidation of metallic elements. As such, the sensitivity of the collection to each of these should be considered as the first criteria to determine appropriate conditions.

One simple environmental approach for many collections materials is to maintain a temperature as cool as possible, with moderate relative humidity in the range of 30 % to 55 %. However, risk to specific materials can vary significantly. Cellulose acetate is quite susceptible to high temperatures and chemical decay, while polyester based films may be quite stable in the same conditions[15]. Early to mid-20th century wood pulp paper often has inherent weaknesses and a rapid rate of decay at warm temperatures; while late 20th century and early 21st century acid free papers produced in accordance with ISO 9706[1] and/or ISO 11108[2] have much slower rates of decay. Many paper materials may be safe at relative humidity up to 60 %, while collections containing silver-based photographs or films may require relative humidity conditions of 55 % or lower to avoid silver oxidation and image loss. Refer to Annex D for other examples of specific media related risks.

Beyond simple vulnerabilities, institutions should also decide what quality of preservation environment they need based on the significance of either the entirety, or portions of, the collections. Archives, special collections, and rare books, among other designated materials, may, due to their unique, fragile, or valuable nature, necessitate better quality preservation environments than circulating or general collections. It is common for institutions to designate different temperature and relative humidity specifications for different collections, with some materials being stored in cool/cold conditions (generally costing more in terms of energy consumption), while other materials may be kept at warmer/room conditions that do not provide as much preservation benefit, but may be more affordable to maintain in terms of energy costs.

Tools such as those listed in Clause 15 can be used to gauge the comparative quality of different preservation environments. Once the necessary or desired environmental condition is determined, it can be used as an underlying guide while considering the environmental influences — positive or negative — presented by the other factors.

The outdoor climate is typically the single largest influence on the interior environment and any energy used in its control. Outdoor temperatures and dew points rarely match exactly what is desired for the indoor environment. Previous guidelines and knowledge focused on holding tight environmental conditions with minimal fluctuation, regardless of outdoor environments, thus largely disregarding the energy consumption required to overcome outdoor temperature and moisture conditions. Recent research and practical experience has shown that appropriate preservation environments can be achieved within a range of temperature and relative humidity specifications, the selection of which can be heavily influenced by outdoor environments.

Without mechanical intervention, interior environments in all buildings will eventually mimic their surrounding outdoor conditions. Outdoor environmental conditions can influence a building through any number of processes, ranging from direct air exchange (opening of doors or windows, or deliberate introduction of outside air through a mechanical system), to radiant energy generated by direct sunlight, transfer of thermal energy due to ambient outdoor temperatures, or moisture incursion through leaks or diffusion.

Not all outdoor environments are detrimental to preservation and energy goals. Though year-round or seasonal warm/humid environments provide dual challenges to reduce temperature and manage dew points appropriately, environments that feature year round or seasonal cool/dry outdoor conditions can provide significant benefit to preservation conditions and can reduce energy consumption in achieving those conditions.

Independent of the buffering or control that the building structure and a mechanical system may provide, the goal in setting temperature and relative humidity specifications should be to appropriately account for outdoor conditions, strive to mitigate risks imposed by the outdoor environment when possible and appropriate, and look to take advantage of natural conditions that are conducive to improved preservation and lower energy consumption.

Examples of generally appropriate temperature and relative humidity specifications relative to outdoor environments (assuming an unoccupied storage environment with mechanical environmental control) may include:

— cool and dry:

  — temperature: 10 °C or lower

  - relative humidity: 30 % minimum, higher if necessary for certain media
- cool and humid:
  - temperature: 10 °C or lower
  - relative humidity: 60 % maximum, lower if necessary for certain media
- warm and dry:
  - temperature: 22 °C or lower
  - relative humidity: 30 % minimum, higher if necessary for certain media
- warm and humid:
  - temperature: 22 °C or lower
  - relative humidity: 60 % maximum, lower if necessary for certain media

Geographic regions with seasonal outdoor conditions — such as a warm and humid condition in one season, with cool and dry conditions another part of the year — can choose to use seasonal temperature and relative humidity conditions to manage appropriate seasonal preservation while reducing energy costs throughout the year.

The influence of outdoor climate conditions on indoor environments is partially determined by the construction and quality of the exterior walls/roof of the building in question. Structures with significant thermal insulation (whether added or as a property of the original wall material) will provide greater buffering capacity against cool or warm outdoor conditions, and will be slow to equilibrate to outdoor temperatures. Structures that lack adequate thermal insulation will respond more rapidly to outdoor temperature changes, and may show indoor temperatures higher than outdoor conditions if energy from direct sunlight transfers through the roof, walls, or windows. Interior storage environments may be influenced by this thermal gain or loss if they are exposed to exterior walls or the roof.

Temperature set points in poorly insulated structures may need to be higher during warm seasons and lower during cool seasons in order to manage energy consumption. Well-insulated buildings will be able to maintain lower temperatures in warm outdoor conditions at less energy consumption, and may have greater capacity for passive operation in both warm and cool outdoor conditions.

Depending on the climate and the building construction, air infiltration through the envelope (whether purposeful or through leakage) may or may not be desirable. Generally, buildings that will operate with mechanical systems to control interior environments will want very little air flow through the envelope, while buildings that function passively may want or need more or less air flow through the structure depending on the season and relative indoor/outdoor conditions.

The vapour permeability of exterior surfaces of structures also directly influences the setting of indoor temperature and relative humidity specifications. Vapour permeability is the measure of how quickly water vapour will diffuse through a particular medium from areas of high vapour pressure to low vapour pressure.

Building exteriors with a high permeability will allow moisture to diffuse through the wall/roof structure quickly, making it more difficult to keep moisture out and dehumidify in humid environments or to maintain interior moisture levels when humidifying.

Building exteriors with a low permeability slow the rate of diffusion, and make it easier to control and maintain appropriate dew points in collections environments through humidification and dehumidification. The use of vapour barriers as low permeability components of wall construction can significantly reduce vapour diffusion, but care should be taken that the vapour barrier is properly located relative to the thermal insulation and typical outdoor conditions and direction of vapour movement.

Exercise caution in choosing temperature and relative humidity set points in buildings with available mechanical systems but high levels of vapour permeability. Active dehumidification in buildings with highly permeable envelopes can increase the rate of moisture diffusion into the structure, causing damage to the envelope and the interior finished surface as moisture evaporates, resulting in efflorescence or weakening of the structure. The reverse problem can occur with active humidification, where vapour is driven through the envelope and evaporates at the exterior surface. This process can cause issues ranging from efflorescence on exterior surfaces to cracking and spalling of the building fabric.

Collections storage that is situated in a below-ground structure or complex (ranging from cave complexes and adaptive reuse of mine facilities to basements, among others) may be affected by ground temperature and moisture levels, rather than outdoor climate conditions. If moisture diffusion and leakage can be controlled, surrounding ground temperatures are often quite favourable to selecting cool temperature specifications at a lower energy cost.

The primary impact of mechanical systems on specifying an indoor collections environment is the ability to control moisture. As discussed in Clause 13, dew point is the key determiner of the safe range of temperature and relative humidity at which a particular environment can be controlled. Once the building envelope capability has been determined, the capacity of a mechanical system to dehumidify and/or humidify will help to set appropriate temperature and relative humidity set points. For example, if the known dehumidification capacity is the equivalent of a 7 °C dew point, and reheat is available for temperature control, the following specifications may be chosen as appropriate in a warm and humid environment:

— temperature: 16 °C to 22 °C

— relative humidity: 38 % to 55 %

At temperatures in the range of 23 °C to 26 °C, the relative humidity would remain above 30 %, but the rate of chemical decay due to high temperatures may be higher than desired. At temperatures lower than 16 °C, the relative humidity will rise above 55 %, introducing risk for metal corrosion and, and at a lower temperature and higher relative humidity, risk of mechanical expansion or mould growth. When choosing specifications, remember that dehumidification, if done via sub-cooling and reheating, uses energy to both dehumidify and reheat the air.

Selecting cooler temperatures at the higher end of an acceptable relative humidity range — for example, 55 % to 60 % — may help to reduce energy costs while still maintaining an appropriate preservation environment. Energy consumption will vary depending on the design of the mechanical system. Consult with facilities and engineering staff regarding the energy use for various temperature and relative humidity specifications.

Mechanical systems and humidifiers are typically designed to provide a certain quantity of moisture per unit of time based on a proposed environment specification. If the humidifier was designed to a maximum potential of humidifying to 21 °C and 30 % (a 3 °C dew point) relative humidity, it would likely be capable of the following example ranges of set points:

— temperature: 12 °C to 21 °C

— relative humidity: 30 % to 54 %

However, if set points of 21 °C and 45 % relative humidity were desired (a 9 °C dew point), the humidifier would be unlikely to have the capacity to provide that moisture output. The equipment may be able to provide less humidification — for example, a 15 °C and 30 % RH environment (–3 °C dew point) — but not more than the maximum dew point equivalent.

In year round or seasonal cool, dry climates, choosing cooler temperature set points with relative humidity at the lower end of the safe range — for example, 30 % to 35 % — can save energy costs on both heating and humidification. In warm and dry climates, maintaining lower relative humidity at moderate temperatures can reduce energy costs on cooling and humidification while avoiding most degradation risks.

Tools such as the psychrometric chart or the Dew Point Calculator from the Image Permanence Institute[1)] can help identify potential appropriate temperature and relative humidity specifications at different known dew point or moisture control capabilities.

It is common, especially if the mechanical system was designed to provide human comfort in occupied spaces, rather than moisture control for collections preservation, that dehumidification may only occur as a byproduct of cooling for temperature control, and that humidification may not be available at all. In these circumstances, it is critical to avoid overcooling in humid conditions or overheating in dry conditions.

Cooling without sufficient dehumidification can result in low temperature and high relative humidity in the storage environment, placing collections at risk of mechanical expansion or mould growth, among other issues. Overheating the environment without humidification may result in higher temperatures with dangerously low relative humidity levels, placing collections at risk of mechanical damage and increased fragility.

Some institutions may have partial environmental control, such as hot water or steam radiant systems that serve to heat interior environments in cool climates. These systems are incapable of providing dehumidification or humidification, and temperature specifications for the storage environment should be carefully chosen to avoid heating more than necessary, which may be detrimental to both preservation and energy consumption goals.

While it is advisable that collections storage environments should not be regularly occupied, many institutions face situations where storage environments are accessible to the public, contain staff workstations, or may be on a shared mechanical system that also serves an occupied space. If this is the case, recognize that human comfort requirements will likely predetermine acceptable ranges of temperature specifications.

For occupied spaces in seasonal climates, slightly improved preservation can be achieved by varying seasonal temperature control, for example between 20 °C to 22 °C. Energy reduction or sustainability goals can still be met by selecting relative humidity set points that follow outdoor conditions — lower relative humidity in dry seasons or climates, higher set points in humid seasons or climates, staying within a moderate range. Effort should be taken to make collections storage environments unoccupied whenever possible, to allow preservation and energy consumption take priority in selection of specifications.

It is not advisable to increase preservation risk in the interest of achieving energy economy. In circumstances where energy reduction is prioritized or required, strive to first achieve savings while remaining within appropriate preservation conditions. Examples include expanding seasonal temperature and relative humidity specifications through reduced temperatures in cool environments, or choosing broader ranges of relative humidity set points as discussed above, or creating microclimates for specific materials with greater sensitivity. Other opportunities for energy economy may exist that can be utilized without increasing the risk to collections preservation; examples of these are included in Annex A.

With air treatment in high-bay repositories, the issue often arises of thermal stratification within the room. Thermal stratification can be controlled by air circulation either through the placement of supply air diffusers at the ceiling and return air intakes near the floor, or through the use of ceiling fans.

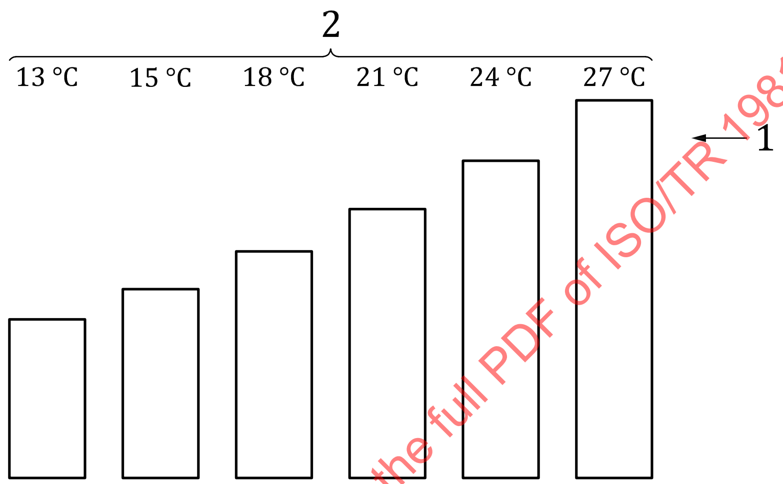
13 Psychrometrics

Psychrometrics, or the study of the properties of gas/vapour mixtures, is critical to understand the relationship between air temperature, relative humidity, and moisture content in an environment. These relationships create the temperature and relative humidity conditions that cause many types of collections degradation. Mechanical intervention in buildings, or “air conditioning”, directly influences these psychrometric relationships by controlling temperature, moisture content, and moisture concentration in a given environment.

1) www.dpcalc.org.

When considering collections storage environments, there are three psychrometric factors that collections professionals shall address — the temperature of the air, its dew point (useful as a representation of moisture content), and the relative humidity. For preservation purposes, knowing and understanding the dew point is the most critical of the three concepts. Not only does it determine the range of temperatures and relative humidity that can be achieved in any given environment, but it is also, from a mechanical perspective, the limiting factor of a mechanical system's ability to provide a particular storage environment.

To gain an understanding of dew point, it is best to begin with the role of temperature. Temperature, simply, is the measure of heat energy in a substance. As the temperature decreases the ability of air to hold water vapour decreases. As the temperature increases the capacity of the system to hold water vapour increases. This concept is illustrated in Figure 2.



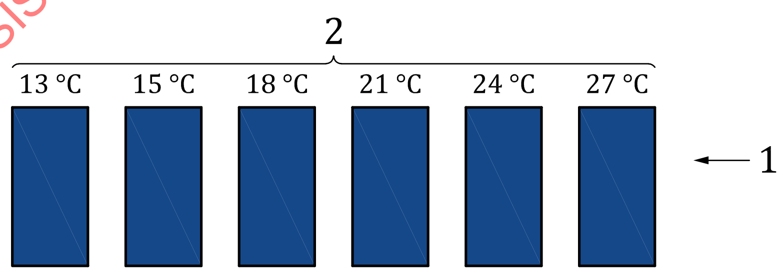
Key

1 capacity to hold water

2 air temperature

Figure 2 — A

In addition to the temperature, environments each contain a particular amount of moisture present in the form of water vapour. This moisture content, the humidity ratio of the system, is constant regardless of the temperature of the system, as shown in Figure 3.



Key

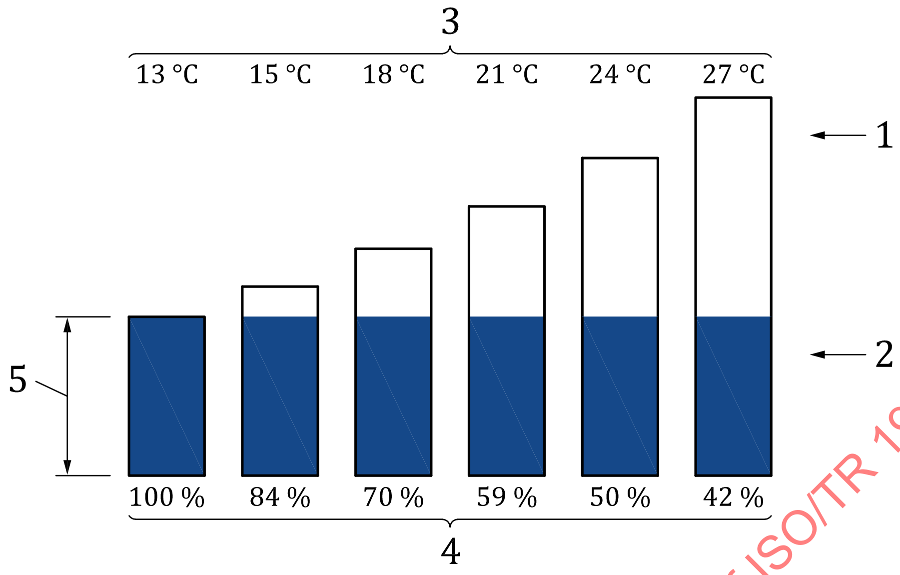
1 actual water present

2 air temperature

Figure 3 — B

Relative humidity is most easily explained as the percent saturation of air, based on the temperature and moisture present. When the relative humidity is at 100 %, the system is completely saturated and can contain no more water vapour, and the corresponding temperature is the dew point temperature — the temperature at which excess water vapour would start to be deposited as droplets of dew. In

Figure 4, the moisture present to create a dew point temperature of 13 °C determines what the relative humidity will be at other temperatures.



Key

1 capacity to hold water

2 actual water present

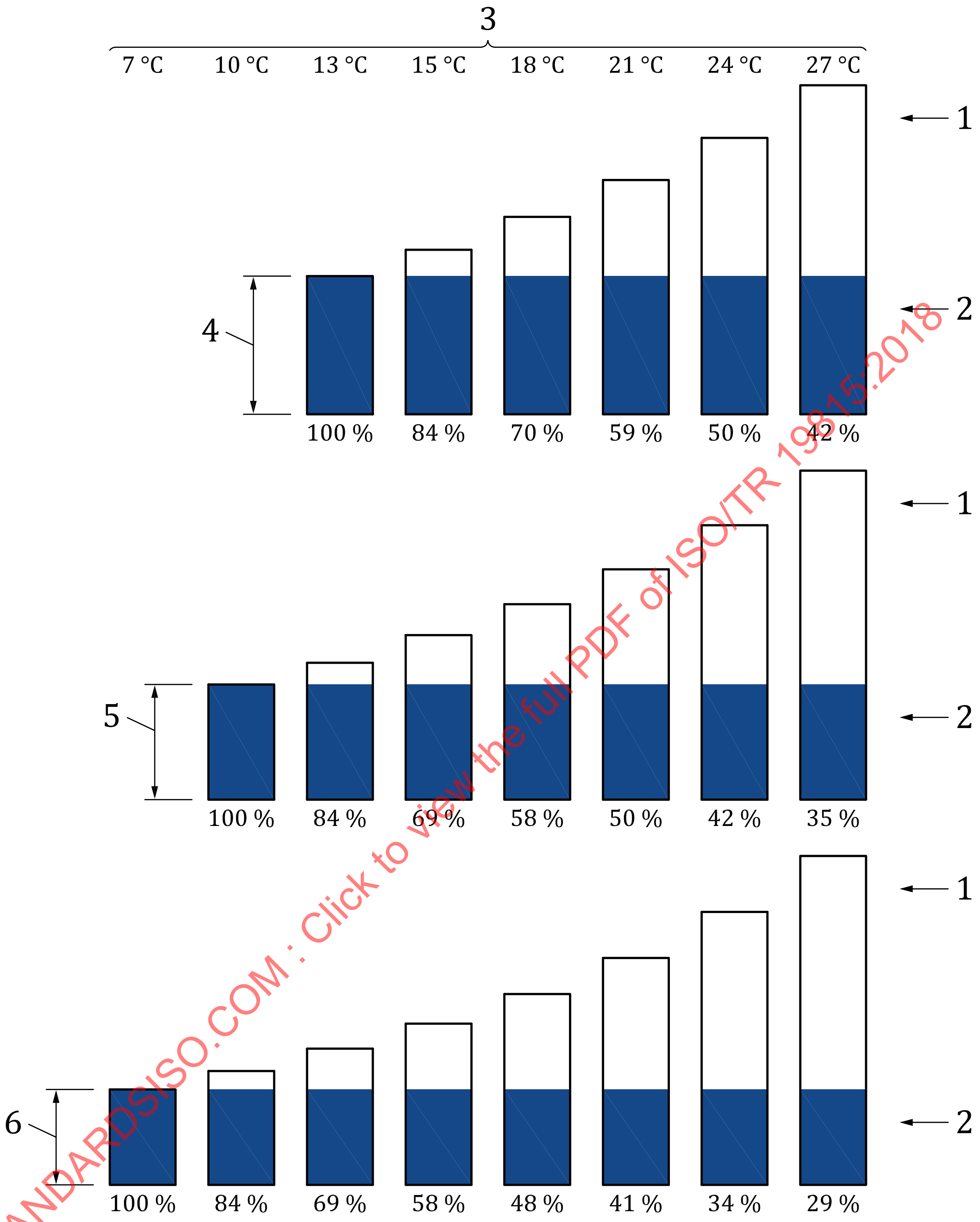
3 air temperature

4 relative humidity

5 absolute humidity (0,009 2 kg/kg)

Figure 4 — C

Notice that, in an environment with a given dew point or moisture content, as the temperature is increased the relative humidity decreases. Conversely, as the temperature is decreased, the relative humidity increases. This psychrometric relationship is the reason why simply controlling temperature in a preservation environment can be risky — the temptation to decrease temperature in order to slow chemical decay, without simultaneously lowering the dew point, can lead to dangerously high relative humidity condition. Figure 5 shows that with a 13 °C dew point it is not possible to achieve a satisfactory temperature/relative humidity combination. At an acceptable room temperature, the relative humidity is too high for long term preservation of collections, while to obtain an acceptable relative humidity, the temperature would have to be raised too high for preservation or comfort. Mechanically dehumidifying to achieve a lower dew point can provide the ability to hold lower temperatures at moderate relative humidity, as shown in Figure 5.



Key

1 capacity to hold water
2 actual water present
3 air temperature
4 absolute humidity (0,009 2 kg/kg)
5 absolute humidity (0,007 6 kg/kg)
6 absolute humidity (0,006 2 kg/kg)

Figure 5 — D

The desire to change the psychrometric and thermodynamic properties of an environment — such as raising or lowering the temperature or changing the moisture content or relative humidity — is where the need for mechanical intervention or air conditioning often appears. Creating a different indoor environment compared to the outdoor environment can be achieved either through passive or active means. Passive solutions might include thermal insulation, vapour barriers or retardants, airtight or minimal air exchange structures, or other approaches to either buffer or slow the impact of the outdoor condition on the indoor environment, or to keep favourable interior conditions from escaping to the exterior (such as buildings cooled by ground temperature). While passive methods are typically favourable in terms of energy consumption, they can be limited by the severity of the outdoor climate and the potential need maintain particular bands of interior environmental conditions.

Active control through the use of mechanical systems powered by various sources of energy (fossil fuels, renewable, etc.) can achieve five basic operations that directly impact preservation:

— raising temperature (heating);

— lowering temperature (cooling);

— adding moisture (humidification);

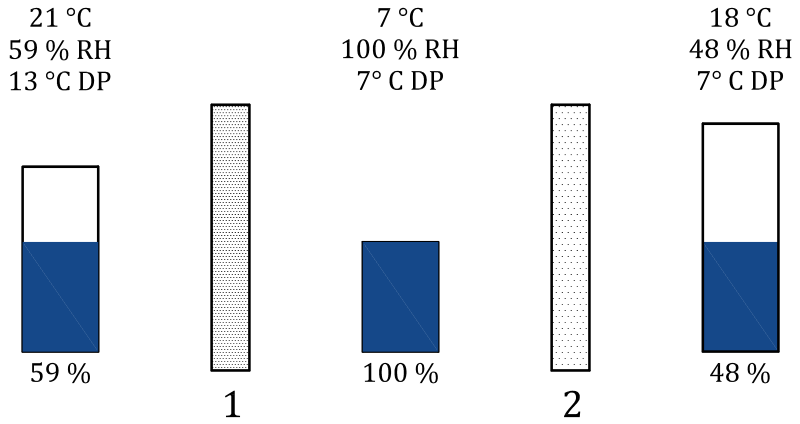
— removing moisture (dehumidification);

— removing particulates or gaseous pollutants (filtration).

As shown above, the temperature and relative humidity conditions of a particular environment, and thus its overall preservation quality, are primarily determined by the moisture content present. High dew point environments will make it difficult to maintain cool conditions at moderate relative humidity, while low dew points create challenges in ensuring materials do not become too dry in “room temperature” conditions. Mechanical systems and design vary greatly among two primary families — forced air and radiant (or water-based) delivery systems. This document will focus on discussion of forced air systems as the more common when looking to accomplish the five operations listed above. Be aware that many historic buildings may only have basic hot water heating systems.

Historically, mechanical systems have most often been designed for human comfort needs or specifications, which weigh heavily toward controlling temperature with less attention paid to moisture control. For preservation needs, moisture control is the critical component, specifically the capability to add or remove moisture to create the desired preservation environment. In climates with year-round or seasonal high dew point conditions, dehumidification — most often through sub-cooling or desiccant processes — is necessary to reduce indoor moisture content. Desiccant systems utilizing media such as silica gel or lithium chloride may be used to create low dew point conditions for cool to cold temperature environments.

More common are refrigerant or chilled water based systems that sub-cool and reheat air. The air stream is sub-cooled below its entering dew point to condense excess moisture out of the system, establish a new dew point condition, and then reheat the air to achieve the appropriate relative humidity in the space. The process is outlined in Figure 6.



Key

1 cooling coil

2 heating coil

Figure 6 — E

Notice that without the reheat stage, the system would send air at 7 °C and 100 % RH directly to the space, creating significant risk for both mechanical damage and mould growth. If the order of these two coils is reversed (and air flow direction remains the same), the system would be unable to dehumidify effectively. Dehumidification control is typically focused on achieving a particular dew point at the dehumidification component, and then adjusting the air temperature to achieve the relative humidity.

For environments that have year round or seasonally dry (low dew point) conditions, mechanical humidification may be necessary. Humidifiers typically inject steam or cool mist directly into the air stream through a variety of mechanical processes, and are meant to maintain a particular relative humidity at fluctuating temperatures by varying the quantity of moisture injected into the air stream.

Mechanical cooling for temperature control, either in conjunction with dehumidification or as a simple cooling process can be achieved via a number of mechanical systems, with the use of refrigerant or chilled water coils and evaporative systems being quite common. Cooling for temperature control alone may be successful in drier climates; in climates with high dew point conditions, simply cooling the air may result in high space relative humidity due to insufficient dehumidification (see Figure 3). The use of evaporative cooling systems, which pass air over a water soaked medium and use the latent heat of evaporation to cool the air, will also result in an increase of moisture content in the air stream, raising the dew point. Evaporative cooling systems cannot dehumidify, and may not be the best choice in climates that require cooling but have high outdoor dew points.

Heating is most often used in climates that have cool to cold seasonal or year round climates, and as shown in Figure 5, are also significant in sub-cool and reheat dehumidification processes. Heat is imparted to an airstream via a number of potential sources, including water coils, electric coils, direct fire sources, and heat exchangers, among others. In cold climates with low dew point exterior conditions, heating may often be paired with humidification due to low available moisture content from outdoors. In general terms, heating and humidification systems are simpler and cheaper to install and run than cooling and dehumidification.

14 Good practices for sustainability

14.1 General

The following are examples of what can be achieved by careful design and attention to detail, following a thorough assessment of the requirements of the building and the collections. It is by no means an exhaustive list, merely illustrative. The environment in the buildings described is mostly controlled by passive means, or has minimal energy consumption. Strategies employed in cold or polar zones include adapting the form of buildings to minimize radiant, convective and evaporative heat loss, but also to maximize the absorption of solar radiation, and to provide protection against the wind. In temperate zones, buildings may be oriented to maximize solar gain in winter and minimize it in summer. Air movement should be encouraged in summer, but protection against the wind should be provided in winter. In hot dry zones, which may be hot by day but cool by night, the form of the building should be compact, possibly arranged around shaded courtyards. Extensive overhangs will provide shading for windows, and the area of exposed glazing should be minimized. Traditional wind towers may be used to promote evaporative cooling and night ventilation. In hot humid zones, where the temperature is fairly uniform throughout the year, similar design solutions may be adopted, but with the emphasis on minimizing solar gain through shading.

14.2 Arnamagnaean Institute archive, Copenhagen, Denmark

The Arnamagnaean Institute houses an important collections of medieval Icelandic manuscripts. The archive store is situated on the North Eastern corner of the first floor of an office block, and has been constructed so as to be well insulated towards the warmed building and thinly insulated towards the outside. The internal walls are made of hygroscopic alumino-silicate fibre blocks, which, together with the contents of the store, serve to buffer the relative humidity to approximately 50 % throughout the year. Over a period of seven years, the temperature has remained within the range of 14 °C to 24 °C and the relative humidity between 48 % and 58 %, with minimal energy input. See Reference [171].

14.3 Territorial archives, St Martin, West Indies

The building is sited to take advantage of the trade winds, which provide natural ventilation and cooling. The main north-facing aspect is combined with a structural outer double skin in composite resin panels to the West and aluminium netting to the North and East. This wall has latticework surfaces in places, to cater for the need for natural light. It provides protection from sunlight on the vertical walls and from the rain on the exposed sides. A broad metal roof overhang shades and protects all the walls, complemented by an upper sunshade. The whole of this level is covered with a double metal covering, which provides an air space between the inside and the outer roof, itself made of sheet metal with waterproofing on a thick insulating layer, ensuring protection from sunlight with a slightly sloping roof. Solar cells on the roof supply a large part of the electrical requirements. See Reference [119].

14.4 Japanese Imperial Archives, Tokyo

The building of the Archives of the Imperial Household Agency in Tokyo was constructed in 1989-1992 according to traditional principles embodied in the Shosoin treasure house in Nara, built in the 8th century AD. The Shosoin has preserved a mixed collections including manuscripts, musical instruments, furniture and textiles in excellent condition for over 1 200 years, largely due to its method of construction and the storage boxes used. The building is constructed from massive timbers, is raised above ground level and has deeply overhanging eaves which protect the walls from driving rain and sunlight. The artefacts are stored in wooden boxes that are raised from the floor, with well-fitting lids.

The archive building is made of wood, has a copper roof and the walls are covered with porcelain tiles. It is naturally ventilated, but dust filters are fitted to the windows and doors. All the archives are stored in lightweight Paulownia wood boxes which buffer the internal RH effectively although the summer RH in Tokyo can rise to 90 %. See Reference [91].

14.5 Jersey Archive, Jersey, Channel Islands

The Jersey Archive is an early example of a passive building that meets the stringent requirements of the Reference [238]. It has thick walls of dense blockwork and a well-insulated roof slab, which is covered by a ventilated sun screen. There is low temperature background heating to control high relative humidity in winter and summer. See References [217] and [176].

14.6 Norwegian National Library, Mo i Rana

Since 1993, the National Library of Norway has had a branch in Mo i Rana, just south of the Arctic Circle. Legal deposit books and motion picture film are stored in a vault carved out of the mountains, where the natural temperature is stable at 8° and the natural relative humidity is stable at 35 %. Since the store is automated, heating for human comfort is not necessary. This is an extreme example of what can be achieved in an extreme climate. See Reference [154].

14.7 Central State Archive of Saxony, Dresden, Germany

The pentagonal archive building dating from 1915 was renovated and a new passive store was built in 2008. The light well of the old building was turned into an atrium by adding a glass roof and the windows were upgraded, which improved the environmental performance. The new building has well insulated walls with minimal openings. This enables a temperature of 18 °C with a seasonal variation of +4 °C and −2 °C, and a relative humidity of 50 % with a seasonal variation of ±5 % and 10 % to be obtained. See Reference [191].

14.8 National Library of Singapore

The ambient temperature in Singapore ranges between 28 °C and 32 °C throughout the year, while the relative humidity generally lies between 60 % and 90 %, reaching 100 % on occasion. The building has been designed with a central atrium which promotes natural ventilation via the stack effect and also provides diffuse natural lighting. There is a roof canopy and horizontal shades which block direct sunlight when the elevation of the sun is greater than 30 °C. Double glazing minimizes heat gain from outside, contrary to its use in cooler climates. Internal conditions are thereby maintained at 23,5 °C and 55 % RH. See Reference [215].

14.9 Archives départmentales du Nord, Lille, France

This passive building has been designed to have efficient insulation (25 cm of expanded polystyrene on the walls and 32 cm on the roof) and to be very well sealed (infiltration 0,045 m^3/m^2h). It has a desiccant dehumidifier which enables it to maintain a temperature of 16° to 22° with a daily drift of <1° and a relative humidity of 50 % ± 10 % with a daily drift of <1 %[153].

14.10 School library, Gando, Burkina Faso

The library is of novel design but constructed from traditional materials: elliptical mud brick walls with a concrete roof with clay pots inserted for light and ventilation, with a ventilated corrugated steel roof above. Although the building would not reach international standards, the internal climate is very much better than it would have been had it just been constructed from mud brick and corrugated steel. See Reference [106].

15 Educational and assessment tools

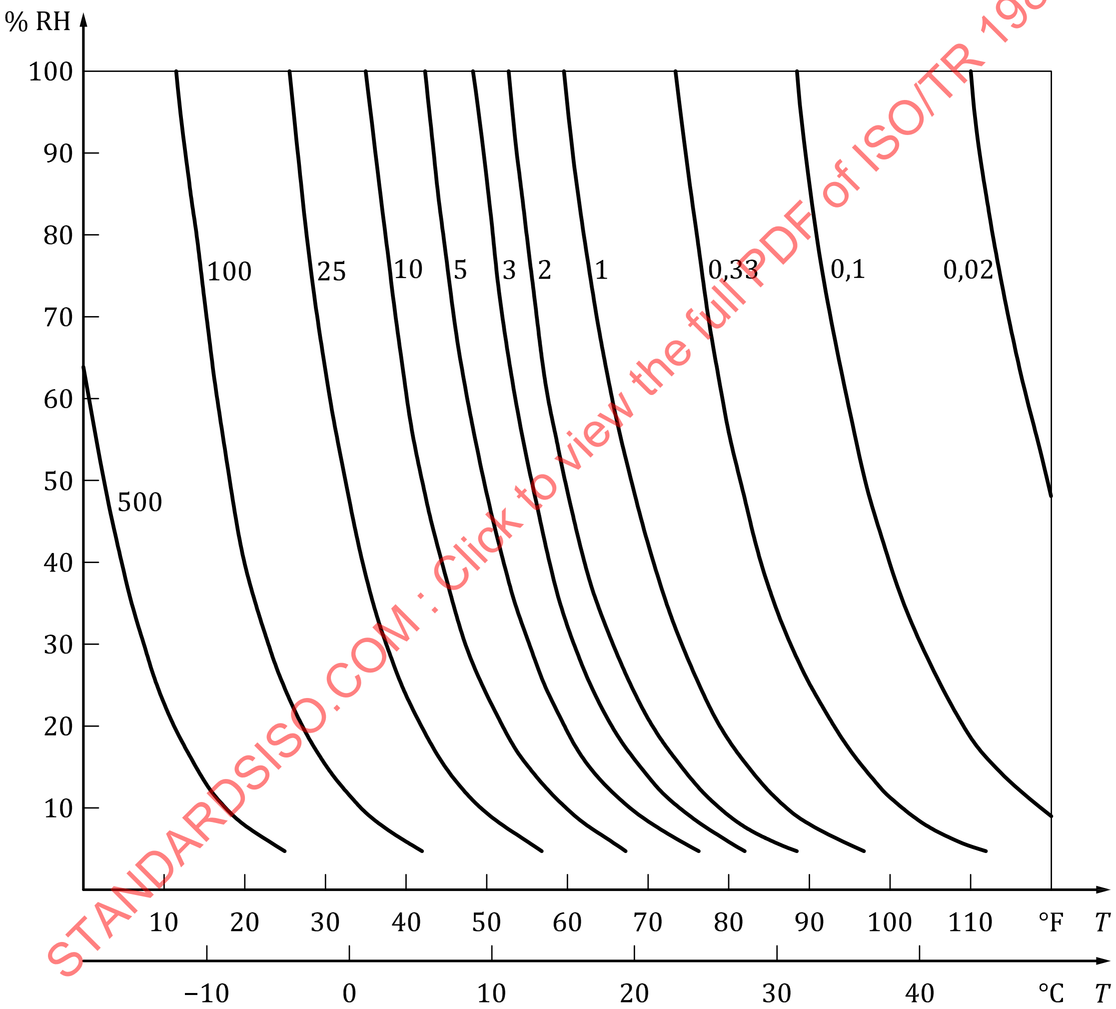
15.1 General

15.1.1 Overview

Several educational and assessment tools exist for quantifying both the potential and calculated preservation impact of choosing various conditions of temperature, relative humidity, and light. These calculators and models are typically based on data for particular media, but have value as reference tools for estimating the effects of temperature, relative humidity, and light for families of similar objects. All of these tools rely on data gathering and environmental monitoring with data loggers to provide the temperature and relative humidity information for input.

15.1.2 Isoperm

The isoperm method, developed by Donald Sebera[198], combines and quantifies the preservation effects of temperature and relative humidity on paper and presents those in graphic form, as in Figure 7, as lines of constant permanence (isopermanence, thus isoperms). In a given environment, an increase in one environmental parameter will result in a change in the relative permanence of paper in that environment — for example, raising the space temperature (without changing the relative humidity) will increase the rate of chemical decay in paper. The isoperm method illustrates that if an exact, corresponding change in the second parameter, in this case a corresponding exact lowering of relative humidity, takes place, then the overall rate of deterioration can remain unchanged from the original condition. The existing or initial temperature and relative humidity can be used to find the initial isoperm for that environment; by plotting a new set of temperature and relative humidity values, collections managers can find the new isoperm line, and the relative positive or negative impact on permanence. The applied value of the method is not in the exact degradation rate for a specific type of paper, but in the comparative rate of degradation at different temperature and relative humidity.



NOTE Source: Sebera[198].

Figure 7 — Isoperm graphic

15.1.3 Preservation index (PI) and time weighted preservation index (TWPI)

The Image Permanence Institute (IPI) conducted research similar to Sebera's isoperm approach on acetate film, and produced two metrics, the preservation index and the time weighted preservation index, as measurement tools to represent the relative rate of chemical decay, based on temperature and relative humidity, for organic materials.

The preservation index (PI)[2)], a calculated rate of chemical decay, represents the number of years to noticeable physical degradation when applied to fresh acetate film stock. However, like isoperms, the greater value is that the PI numbers, when applied to organic materials in general, reasonably accurately represent the relative rate of decay, or put another way, the quality of the preservation environment. Essentially, if an environment's specific temperature and relative humidity yield a PI of 50, and a change in environmental conditions yields a PI of 100, the new environment can be understood to have a preservation condition that will double the lifespan of organic materials, or that will halve the original rate of chemical decay.

The time weighted preservation index (TWPI) is IPI's answer to the difficulty that both isoperms and the PI are based on single sets of temperature and relative humidity conditions. These decay metrics work well for environments that are capable of maintaining flat-line conditions where temperature and relative humidity conditions rarely change. In reality, many collections storage and exhibit facilities have temperature and relative humidity conditions that vary significantly over the course of a year, making the use of these metrics less reliable for assessment of real life, changing environments. IPI developed the TWPI, which integrates the temperature and relative humidity values as they change over time into a single estimate of the cumulative effects of the environment on the rate of chemical decay, to allow for a more complete understanding of chemical degradation in preservation environments.

IPI has also developed metrics that estimate the relative risk of other environmentally induced decay, such as mechanical shape change (physical expansion and contraction due to moisture content), mould growth, and metal corrosion. The mechanical damage metric, which uses the estimated percent equilibrium moisture content (EMC) of hygroscopic materials based on ambient relative humidity conditions, assesses risk based on maximum and minimum levels of moisture in the object – an EMC that is too high will pose a risk of mechanical expansion and corresponding physical damage, such as swelling and warping of papers, while one that is too low will pose a risk of problems such as splitting and splaying in vellum materials or increased handling risk for brittle materials. The mould risk metric compares temperature and relative humidity conditions in an environment against germination rates for common mould strains, and calculates the progress toward germination. The metal corrosion metric uses the maximum % EMC measured against time at those conditions, to estimate the relative risk of oxidation reactions (corrosion) in iron, silver, and copper alloys.

The Image Permanence Institute's Dew Point Calculator can be found at: http://www.dpcalc.org/

15.2 Environmental management tools and assessments

15.2.1 General

A number of useful educational tools can be found online. See Reference [168]. These are useful for explaining fundamental concepts in climate calculations such as heat capacity, latent heat, saturated vapour pressure, etc. and the physical principles that underlie the behaviour of buildings. Several calculators permit the user to explore the effects of changing parameters such as the target temperature and relative humidity on energy use.

15.2.2 Fundamental microclimate concepts

A glossary of the microclimate variables and units used in conservation physics.

http://www.conservationphysics.org/intro/fundamentals.php

15.2.3 Air exchange between an enclosure and its surroundings

This explains the concept of air exchange in buildings and display cases, its importance in specifying storage environments, and how it can be measured.

http://www.conservationphysics.org/airex/airexchange.php

2) The preservation index calculation is available for free at www.dpcalc.org.

15.2.4 Calculator for atmospheric moisture

A tool that calculates the wet bulb temperature, dew point, vapour pressure, mixing ratio and moisture concentration, given the dry bulb temperature and relative humidity.

http://www.conservationphysics.org/atmcalc/atmocalc.php

15.2.5 Calculator for energy use in museums

A tool that calculates the energy use of a building month by month, knowing the external conditions and the desired internal conditions, and the quality of the insulation and the air exchange rate.

http://www.conservationphysics.org/atmcalc/energyusecalc.php

15.2.6 Calculator for conservation heating

A tool that calculates the temperature needed to obtain a desired value of the relative humidity, knowing the ambient temperature and relative humidity.

http://www.conservationphysics.org/atmcalc/consheatcalc.php

15.2.7 Calculator for dehumidification energy load

A tool that calculates the energy consumption of a dehumidifier that is set to maintain a given relative humidity in a building, given the monthly ambient temperature and relative humidity, buffering capacity and air exchange rate.

http://www.conservationphysics.org/atmcalc/dehumidcalc.php

Annex A
(informative)

Energy economy

Active control of preservation environments for collections storage requires an input of energy, typically at multiple components and for various operations within a mechanical system or building. The most sustainable preservation environments are those that are capable of running primarily passively, where purpose-built structures (above- or belowground level) with appropriate thermal and vapour buffers for the outdoor or surrounding climate can maintain dew point, temperature, and relative humidity conditions within the institution's selected parameters. While facilities along these lines have been shown to work in multiple climate regions, virtually all facilities require some degree of energy input — if only for lighting purposes and human safety requirements — and many will have some opportunity for greater energy economy than what they are currently achieving.

Several guiding principles should be followed when considering opportunities for achieving energy economy within preservation environments.

— Energy economy should not be achieved at the expense of appropriate preservation quality.

— When possible, aim for passive control of environments.

— The risks associated with experimentation with energy saving measures should be assessed and managed accordingly.

— Excess energy consumption is common.

— Excess energy consumption is often not self-announcing.

Consideration of sustainability and energy economy in preservation environments often requires a reevaluation of what constitutes a properly functioning facility. In the past, success may have been determined by the ability to maintain the designated set point conditions with little regard for how they were achieved, the amount of energy used, and the efficiency of that use. As national and international expectations for sustainability and energy economy have changed, so too has the need for cultural institutions to meet these expectations. Preservation and collections storage environments are often among the most energy intensive functions of a cultural institution. Institutions have the responsibility to explore options for energy economy that work within the preservation goals.

The operational goal is an optimal preservation environment — one that achieves the best possible preservation for collections at the least possible energy cost that is sustainable over time.

Passive operation has the highest potential of energy economy of any environmental control option, and simply means that the collections environment is created with little or no mechanical intervention. Collections environments may be fully passive, such as historic structures or belowground storage environments that use ground temperatures and natural moisture levels to maintain storage conditions, or partially passive, such as purpose built heavily constructed buildings that use combinations of thermal insulation, vapour barriers, and passive ground energy transfer, with minimal mechanical intervention, to condition the interior.

Structures may also be fully passive with the intent (or need) to allow outside air to circulate freely via windows or doors when appropriate, and to restrict it when outdoor conditions pose a significant threat. In these cases, minimal air circulation via fans or other small equipment may be employed to keep air moving and reduce the likelihood of unwanted microenvironments or mould germination.

Seasonal passive operation may also be an option in certain climates, where mechanical control may be necessary during a warm/humid season, but a building may be allowed to run completely or partially passively during a cool/dry season. Based on building characteristics, mechanical system availability and capability, and the preservation needs of the collections, institutions should carefully consider when and if they may need or desire to manage a passive environment. When viewed from the perspective of energy economy, the goal should be to look for opportunities to reduce mechanical intervention and allow a collections environment to run as passively as appropriate.

Institutions should be wary of sustainability or energy economy solutions that are solely equipment based. While modern mechanical components or systems are often significantly more energy efficient than their predecessors, even the most modern or efficient equipment can be run sub-optimally if used inappropriately or if required to remove a greater energy load than necessary. Typically, the goal should be to achieve the optimal operation with the current mechanical system in place, and allow that process to inform what future equipment changes or upgrades might be appropriate or necessary to either further improve the preservation environment or improve energy economy. If new equipment is selected, care should be taken to ensure that its operation is optimized.

As noted in Clauses 6 and 7, using a range of acceptable preservation specifications, especially in seasonal environments, can be a significant opportunity to achieve energy economy and improve seasonal preservation quality. The goal is to use less energy when outdoor conditions may be favourable to achieving the desired interior environment. The safest way of achieving this in a storage environment is typically to allow an interior collections storage environment to naturally drift toward the seasonal limit (whether higher or lower in temperature or relative humidity). By choosing cooler interior set points and lower (but still within the safe range) relative humidity during cool/dry seasons, institutions can often save energy on both heating and humidification. During warm/humid seasons, institutions can choose to use higher relative humidity that are still within a safe range for materials but that require less overall dehumidification, saving energy at what may be a minimal impact to the overall preservation quality.

Although seasonal conditions vary globally, regions may experience cool/humid and warm/dry seasons, or very little seasonal change at all. Four general principles apply when considering energy economy:

— choose cooler temperature set points when outdoor conditions are cool (while maintaining appropriate relative humidity);

— choose warmer temperature set points when outdoor conditions are warmer (while maintaining appropriate relative humidity);

— one key exception: warmer temperature set points will use more energy if you are dehumidifying using sub-cool and reheat;

— choose higher relative humidity set points when outdoor conditions are humid or whenever dehumidifying;

— choose lower relative humidity set points when outdoor conditions are dry or whenever humidifying.

The seasonal transition between these conditions may show regular variation in interior temperature and relative humidity conditions. Research has shown that, generally, rates and degrees of environmental variation have little impact on materials preservation as long as the environment remains within the established appropriate seasonal limits for temperature and relative humidity as laid out in the temperature and relative humidity specifications[137]. Before instituting seasonal set points, work with facilities/engineering colleagues on the environmental team to ensure that these general guidelines will work with the institution's specific mechanical system design and operation.

It is not generally advisable to use strategies such as outside air economizing or “free-cooling” — where greater quantities of outside air are brought directly into the interior environment via the mechanical system — in collections environments. These strategies are typically run by either a sensible temperature or enthalpy (total energy content) control that does not appropriately account for the actual moisture content being brought into the building. Any outside air economization strategy should use the difference between exterior and desired interior dew points as one determining factor. Be aware that the amount of time where both the outside air temperature and dew point are beneficial to the interior environment can be quite small.

In instances where a small percentage of the collections require more energy intensive environmental conditions (such as cold storage for acetate and nitrate films, or a narrowed relative humidity range for vellum or parchment materials), these conditions are typically more efficiently achieved through the use of microenvironments rather than conditioning an entire collections environment to more stringent conditions. Microenvironments, whether buffered casing and containers, or small room environments, allow appropriate environmental conditions for the materials in question, while restricting any additional energy usage to the smaller storage volume. Note that some microenvironments may be achieved through entirely passive means (such as cabinetry with gaskets, multilayer storage, use of silica gel and like agents to buffer moisture), which further improves their energy economy.

Many types of energy inefficiency do not manifest themselves in normal observation of environmental conditions. Even if collections environment temperatures and relative humidities match the desired specifications, different mechanical processes can use more energy than necessary in creating these conditions. Though there are a number of possibilities for inefficient performance, some common operations where excess energy can be used that will not necessarily appear in the collections environment conditions include:

— excess use of outside air;

— excess air circulation;

— excess mechanical operation;

— unnecessary peak operation;

— over-filtration;

— incorrect seasonal dehumidification.

Outside air is used in nearly all buildings as a means of maintaining appropriate air quality for human occupation, providing air exchange to remove interior pollutants, maintaining positive pressurization compared to the exterior environment, and general ventilation. It is common for collections storage environments to use similar quantities of outside air to an office or public space. However, if unoccupied, collections storage environments generally require less outside air than similar sized occupied spaces. Collections do not require fresh outside air for health purposes, and reduction in outside air quantities can reduce the overall load on filters (both particulate and gaseous) and reduce the amount of temperature and moisture control work that must be done. Carbon dioxide monitoring systems and/or scheduled operation of the outside air intake can reduce total quantities of outside air brought into the system while still providing appropriate quantities of fresh air.

Institutions should strive to use the minimum amount of outside air necessary in storage environments — this quantity may be quite different from recommended outside air quantities for regularly occupied spaces. Even where holding spaces are occupied during the working day offset will often be possible out of hours.

Collections environments rarely require constant air circulation. Depending on the surrounding conditions or the quality of the exterior envelope, energy economization strategies such as controlled, risk managed mechanical systems shutdowns and setbacks may be appropriate. Control sequences that run mechanical system fans at full speed and constant fan operation are common, and are rarely optimal for energy economy. In cases where inappropriate microenvironments exist or are a concern, some air circulation can assist in mitigating these conditions and protecting collections from extreme environmental conditions and outbreaks of mould.

A shutdown is considered to be a complete powering down of the mechanical system, usually according to a set time schedule (a certain number of hours per day). It may also incorporate safety limits so that, in the event of excessive fluctuation of internal conditions, the mechanical system can turn back on to overcome the environmental change.

Setbacks can take the form of either reductions in fan speed with a variable frequency drive (either on a schedule or demand based) or adjustments in set points, with temperature adjustments being most common.

Both strategies seek to achieve more passive operation of the collections environment – shutdowns by allowing the space to drift and purposely allowing some natural daily fluctuation of temperature (normally 1 °C to 2 °C) and relative humidity conditions, and setbacks by only using as much air circulation or conditioning as is necessary to maintain the environment, more effectively using the buffer of the building envelope as the initial environmental control. There is no prescriptive approach for either strategy — rather, the goal is to experiment with operating speeds and times to determine the minimal fan operation necessary to maintain the preservation environment within a reasonable variation of conditions.

The ratio of collections to air in a particular volume of space can also have a significant influence on the amount of energy necessary to maintain environmental conditions. Library and archival collections, due to their ability to hold both heat energy and moisture, can buffer their own environments if there is a sufficient volume of material compared to the volume of air. The buffering capacity varies, but in high density storage environments, especially utilizing compact shelving, the buffering capacity can be great enough to aid in other energy economy practices such as shutdowns and fan speed setbacks, as well as reducing the overall volume of air in the space that must be conditioned.

Unnecessary "peak" operation is commonly seen in environments where only small portions of the year are spent at the most extreme outdoor conditions (the most extreme yearly conditions, whether hot, cold, dry, or humid). Mechanical systems are commonly designed to be able to overcome peak temperature and moisture extremes. If they operate in that same peak operation even during non-peak conditions, there will likely be energy wasted. Strategies for overcoming this vary, from reducing air flow to using adjusted set points during non-peak operation. The environmental team should work together to determine how mechanical systems should run during non-peak outdoor conditions.

Filtration of unwanted particulate or gaseous media from the air stream requires energy consumption (via fan operation) to move air through the filter media and also require periodic replacement of the filter media. Outside air is typically the single largest source of both particulate and gaseous pollutants. Filtration for collections environments may consist of three steps:

— Rough particulate: G4 (EN 779) or MERV 8 equivalent, standard pleated filters;

— Fine particulate: F7 (EN 779) or MERV 13 equivalent or better, box or bag filters;

— Gaseous filtration: Carbon, potassium permanganate, or other filter media. Used for removing acetic acid, nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone, and other gaseous pollutants (see Annex E).

The first two are standard on most mechanical systems designed for preservation environments, while gaseous filtration is most often found in urban environments or where there is specific concern that collections or structural elements will off-gas pollutants. In the interest of energy economy and efficiency, particulate filters should be changed regularly, either on a time schedule or based on an operational indicator, such as air pressure drop across the filter surface (as filters become full, the pressure drop increases).

Gaseous filtration is energy intensive in terms of the air flow required to move air through the filter media, and expensive in terms of replacement costs for the filter media. Due to the difficulty and expense of replacing the filter media, it is common to find gaseous filtration banks that are either plugged or that have been completely removed. Blocked filters can cause either an increase in energy consumption as fans run harder to move air across them, or can potentially cause difficulty holding environmental conditions in the space if the fan cannot move enough air through the blocked filter. If the gaseous filter bank has been completely removed, fans may continue to operate at the high speed required when the filter was in place. Reduction of outside air quantities can significantly reduce the volume of gaseous pollutant to be filtered out, and recent research (see Reference [240] suggests that the preservation benefit of gaseous filtration may not be sufficient enough to incur the energy/filter media costs. Internal pollutant monitoring is recommended to help determine the potential need for gaseous filtration.

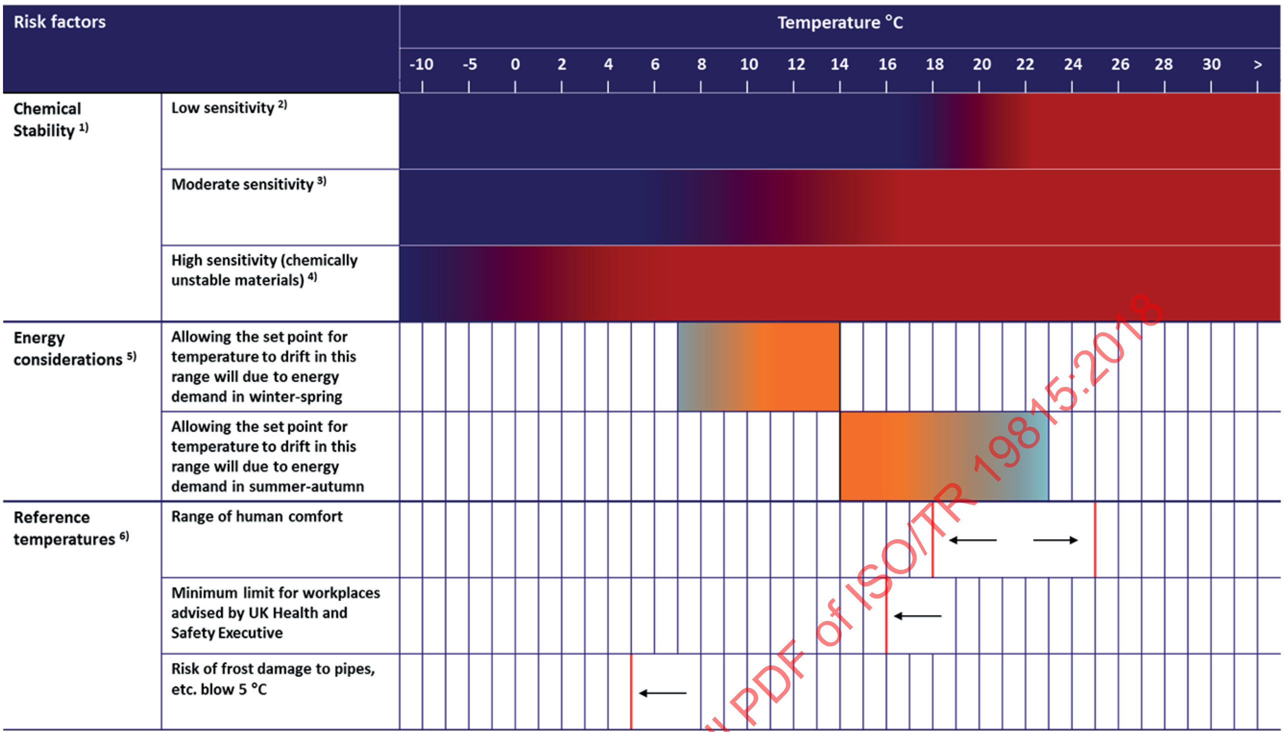
In addition to suboptimal seasonal temperature and relative humidity specifications, certain seasonally inefficient mechanical processes related to temperature and moisture control can reduce energy economy. While these can vary from inefficient and inappropriate seasonal use of preheating to suboptimal use of face and bypass systems, one of the most common issues is inappropriate dehumidification operations during dry seasons. In geographic regions with seasonal humid and dry conditions, it is common for dehumidification to be necessary for at least part of the year, often accomplished either through sub-cool/reheat or desiccant dehumidification. It is equally as common to find scenarios where, in the interest of making sure that dehumidification is always available, the cooling coil or desiccant dehumidifier operates as though it is dehumidifying even when outdoor dew points are well below the desired interior dew point and there is no interior source of moisture. The result is significant excess energy usage. Sub-cooling when there is no need to dehumidify means that the downstream heating coil may have to work harder to either accomplish the appropriate supply air condition to either cool, or worse yet, to heat the space. In the case of a desiccant dehumidifier, heat will be introduced to the air stream that will likely require more energy to cool to an appropriate supply air condition than if the desiccant system had been offline. In both cases, the benefit of any humidification that may be performed downstream could be negated, as the dehumidification process may remove this moisture the next time the air passes through the system. Ensuring that the mechanical system is only doing the minimum amount of work necessary — especially considering seasonal operation — can quickly achieve significant improvements in energy economy.

Mechanical system efficiency and economy can also be influenced by environmental factors in the collections environment. Beyond air and moisture infiltration through the envelope, lighting is typically the single largest influence on energy loads from a space. Most forms of lighting incur energy consumption twice: once to power the light source itself, and again at the mechanical system to remove heat generated by the light. While the increasing prevalence in LED fixtures alleviates some of the severity of the energy use and heat generation, efficiency in use should be practised regardless of energy consumption, and LED lighting can still cause light related damage to collections. All institutions should look for ways to practise economy in lighting, whether implementing better protocols regarding when and which lights are turned on, or exploring automatic control options such as motion sensors or timers. Out of hours security lighting may consume amounts of energy comparable to that used during opening hours.

Annex B
(informative)

Impact of temperature

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



1 Chemical stability: these ranges show higher temperatures leading to accelerated degradation rates, indicated by the gradation from blue to red.

2 Low sensitivity: materials with reaction rates less affected by temperature, e.g. ceramic, glass.

3 Moderate sensitivity: materials with reaction rates moderately affected by temperature, e.g. paper.

4 High sensitivity: materials with reaction rates highly affected by temperature, e.g. plastics, film.

5 Energy considerations: these ranges show the energy demand, with light blue indicating lower energy demand and orange indicating higher energy demand.

6 Reference temperatures: reference temperatures are included for the purpose of comparison. The human comfort range is between 18 °C and 25 °C, while the lower limit for human occupation in the workplace is often set by national standards. There is no lower limit for exhibitions that take place in conditions outside the human comfort range. Below 0 °C there is an increasing risk of frost damage to the building structure, frozen pipes, etc. Based on this, the 5 °C is a precautionary lower limit based on expectations that there will be variations in spaces and over time.

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

NOTE 2 If the period of exposure is sufficient for thermal response (minutes to hours for most collections), there is no difference in the potential for physical damage between short and long periods of low temperature, except in a few special cases, such as migration of plasticisers from plastics or of lubricants from magnetic tape.

NOTE 3 Many ethnographic and decorative arts collections items have been observed during exposure to −30 °C in collections in cold countries or following the use of low temperature pest control. The consensus is that no visible damage beyond a few small fractures has occurred to the great majority of items.

NOTE 4 Low temperatures can cause embrittlement due to a T_g change.

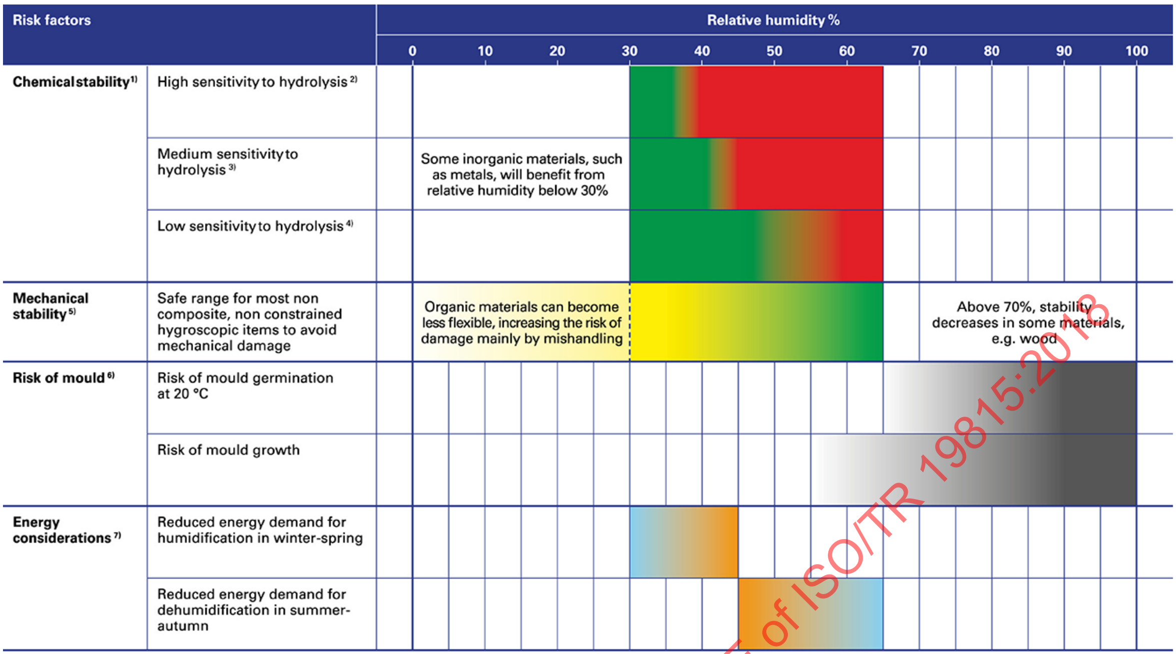
NOTE 5 See BSI/PAS 198:2012, Figure C.1[46].

Figure B.1 — Relative risk of damage and deterioration due to temperature

Annex C
(informative)

Impact of relative humidity

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



1 Chemical stability: these ranges show higher RH leading to accelerated moisture induced chemical degradation rates, indicated by the gradation from green to red.

2 High sensitivity to hydrolysis: materials with a relatively high presence of hydrolysis sensitive chemical groups within the polymer chain, e.g. leather and textiles previously acidified by pollution, cellulose acetate film.

3 Moderate sensitivity to hydrolysis: materials with a relatively moderate presence of hydrolysis sensitive chemical groups within the polymer chain, e.g. some wood pulp papers.

4 Low sensitivity to hydrolysis: materials with a relatively low presence of hydrolysis sensitive chemical groups within the polymer chain, e.g. rag paper, polyester film.

5 Mechanical stability: the area shown in yellow indicates the range within which the risk of physical damage is higher, while the area shown in green indicates the range within which the risk of physical damage is lower. In the area below 30 % RH, the risk of damage to organic materials by mishandling is increased despite the reduced rate of chemical degradation. In the area above 70 % RH, for some materials e.g. wood, mechanical stability decreases.

6 Risk of mould: the areas shown in grey indicate a precautionary upper limit of 65 % RH to avoid mould germination at 20 °C. The gradation to darker grey indicates increasing risk of mould growth and faster germination times. Note also that mould germination and growth are also temperature dependent.

7 Energy considerations: these ranges show the energy demand, with light blue indicating lower demand and orange indicating higher demand.

NOTE 1 Current research on simple laminar test composites of traditional materials (e.g. wood, oil paint, gesso and gelatine) suggests that at least ± 15 % RH fluctuation is needed to approach yield or fracture due to either tension or compression in one of the layers. Some collections items are more sensitive in their structure than test composites, and some materials weaken with age, so some aged collections items can fracture with smaller fluctuations.

NOTE 2 At 75 % RH and above, the dimensional change due to each 5 % rise in RH increases exponentially. Restrained layers, especially wood, begin to suffer irreversible compression, causing greater sensitivity to fracture during periods of low RH. Gelatine in, for example, animal glues, paper size and photographic image layers begins to change from a tough strong material to a sticky weak material, causing glued assemblies to become detached and photographs to stick together. Paper and parchment begin to release manufacturing strains, causing permanent cockle. All forms of metal corrosion increase their rates several times.

NOTE 3 See Reference [146].

NOTE 4 See BSI/PAS 198:2012, Figure D.1[46].

Figure C.1 — Relative risk of damage and deterioration due to relative humidity

Annex D
(informative)

Material damage associated with temperature and relative humidity

Guidance on the damage and deterioration and the risks associated with temperature and relative humidity (RH) is given in Table D.1 for a representative selection of materials found in collections.

The damage and deterioration and risks described are based on evidence from referenced research publications, details of which are given in the bibliography. It is recognized that some entries are more complete than others. Where entries are more complete, this reflects an existing body of published empirical evidence. In some areas, however, it is clear that further evidence is required.

Many collections items are composite objects with a structure that combines a number of different materials. Each element in these diverse structures is vulnerable to change and degradation with time, often as a result of adverse and varying environmental conditions over long periods. These objects are often most affected by fluctuating RH over short periods. Furthermore, composite objects behave in a more complex manner than the sum of their individual components. Historic repairs and previous conservation work can also increase the vulnerability of a collections item.

Table D.1 — Material damage and deterioration and risks associated with temperature and relative humidity for selected material types significant to archive or library collections from Reference [46]

Material	Damage and deterioration	Risk	Evidence
Film	— Low RH (below 30 %): will cause loss of moisture affecting the gelatine and emulsion layers, leading to flaking and/or delamination. — Sustained high RH (above 50 %): gelatine layer becomes soft and sticky, bio-deterioration. — High RH (above 50 %):and temperature above 7 °C will accelerate the rate of chemical decay of colour image, nitrate and acetate film; and can cause chemical deterioration, e.g. leaching of plasticizers.	— Permanent film deformation (brittleness or curl); loss of information; "blocking" of film reels (gelatine layer adhering to enclosures or adjacent sections of film). — Destruction of emulsion due to fungus growth. — Vinegar syndrome in acetate film. — Loss of information.	BS 1153[237] ISO 18934[14] Reference [131] Reference [144]
Ink: digital ink	— The extent of change depends on the substrate (usually paper), the composition of the ink, e.g. dye-based or ink-based, and the interaction between them. — Temperature: at 20 °C to 30 °C (if RH is below 60 %), most digital inks are stable. — High temperature (above 45 °C): dye migration. — High temperature (above 35 °C): at 50 % RH density gain and yellowing of paper support. — High RH: above 60 % RH, dye migration; a shift at 60 % at average temperatures (16 °C to 18 °C for some dyes).	— Gradual change of digital image quality, loss of image, and an associated loss of intrinsic value.	Reference [48] Reference [90] Reference [103] Reference [134]
Ink: iron gall ink	— Data suggest iron gall inks are susceptible to both oxidation and hydrolysis. The latter is especially significantly accelerated by high RH and high temperature. Long term preservation is achievable by cooled storage or cold storage similar to those for rosin-sized acidic papers. The present level of knowledge suggests limits of ±10 % RH and ±5 °C in any time interval.	— Ink corrosion ultimately leads to loss of material support, which results in loss of areas with ink application and loss of information. In earlier stages of deterioration, ink lines are prone to cracking during handling.	Reference [112]
Leather	— High temperature: above 20 °C, increase in the rate of chemical-induced degradation; oxidation of protein and tannins leading to loss of stability; and hardening. — Low RH: below 50 %, desiccation leading to breaks and other physical changes occur. — High RH: above 60 % mould can develop; and shrinkage occurs, leading to embrittlement.	— Structural deterioration and loss of protein structure; staining and discolouration due to mould growth; loss of intrinsic value.	Reference [43] Reference [51]

Table D.1 *(continued)*

Material	Damage and deterioration	Risk	Evidence
Paper	— High RH: above 65 %, increased risk of bio-deterioration. Acid hydrolysis significantly accelerates with RH. — Acidic paper and paper containing iron gall ink generally degrade at 10 times the rate of rag and alkaline/pseudo-alkaline sized paper, and require lower temperature and/or RH for long term preservation. — Fluctuations of ±10 % RH and ±5 °C are considered acceptable.	— Brittleness due to hydrolysis or oxidation. Discolouration due to chemical degradation or photo-induced degradation. Stiffness of bindings if RH is below 25 %. — Mechanical damage leading to loss of original material, information and intrinsic value.	Reference [41] Reference [138] Reference [198] Reference [207] Reference [230]
Parchment	— Setting environmental conditions depends upon the proportion of collagen and gelatine in the parchment. — High temperature: causes structural changes in collagen and predisposes parchment to gelatinization. — Low temperature: temperatures below 0 °C will induce structural changes in collagen. Effects on historic parchment have yet to be investigated. — Fluctuating RH: increased cockling and distortion leading to separation of paint and ink layers from support. — High RH: above 65 % there is an increased risk of biodegradation. — 38 % to 45 % RH produces a water content of approximately 14 %, which reduces internal stress. — Low RH: RH below 30 % increases stiffness of bindings.	— Inappropriate conditions will cause permanent distortion leading to loss of information and decrease in intrinsic value of the collection item.	Reference [42] Reference [61] Reference [87] Reference [117] Reference [196]
Photographs	— High temperature: dye fading, accelerating degradation, e.g. vinegar syndrome. — Low RH: below 20 % will cause desiccation of the component parts. — High RH: above 50 % leads to rapidly increased rates of hydrolysis of cellulose acetate and nitrate-based film. Silver images, particularly with residual chemical agents, will suffer redox reactions, silver mirroring, sulfiding, loss of transparency in glass negatives. — High RH: above 70 % can suffer micro-organism growth, softening and adhesion of the gelatine layer. — Fluctuating temperature and RH: paper prints, film, gelatine, albumen can suffer condensation, differential expansion/contraction, deformation, desiccation, crazing.	— Loss of physical properties and loss. — Brittleness, breaking, deformation; delamination of cellulose acetate bases, paper prints, gelatine, albumen, glass negatives of collection items. — Disfiguring stains, photographs sticking together; loss of information and intrinsic value. — Breaking, leading to loss of information and intrinsic value.	ISO 18934[14] Reference [118] Reference [133]

Annex E
(informative)

Sources of pollutants and their impact on materials significant to archive or library collections

Guidance on sources of pollutants and the effect of pollutants on selected materials significant to archive or library collections is given alongside supporting research references in Tables E.1 to E.4. In particular:

a) sources of internally generated pollutants are given in Table E.1;

b) pollutant material interactions in enclosures are given in Table E.2;

c) pollutant material interactions in open storage or open display are given in Table E.3;

d) approximate threshold concentrations for a number of pollutant material interactions are given in Table E.4.

Table E.1 — Sources of internally generated pollutants

Source	Pollutant	References
Acrylic and nitrocellulose paints	Acetic acid (ethanoic acid) Solvents	Reference [242] Reference [210]
Cellulose acetate collection items, cellulose triacetate film		Reference [23] Reference [24] Reference [33] Reference [66] Reference [243] Reference [183]
Cellulose nitrate collection items and photographs	Camphor Formaldehyde (methanol) Nitrogen	Reference [65] Reference [102] Reference [151] Reference [176] Reference [231] Reference [232]
Plastic, rubber	Acid vapours	Reference [111]
Poly-isoprene rubber (carpet backing), vulcanized rubber, wool and certain sulphide minerals	Reduced sulfur gases	Reference [245] Reference [62] Reference [246] Reference [222]

Table E.1 *(continued)*

Source	Pollutant	References
Poly(vinyl acetate)	Acetic acid (ethanoic acid)	Reference [38] Reference [63] Reference [79] Reference [80] Reference [200] Reference [210]
Poly(vinyl chloride)	Hydrochloric acid	Reference [105]
Resins/coatings	Acetic acid (ethanoic acid) Formic acid (methanoic acid) Solvents	Reference [210] Reference [213]
Wood	Acetic acid (ethanoic acid) Formic acid (methanoic acid)	Reference [26] Reference [247] Reference [248] Reference [242] Reference [62] Reference [71] Reference [76] Reference [85] Reference [111]
Wood-based panels (sealed with urea-formaldehyde or phe-nol-formaldehyde resins)	Formaldehyde (methanol)	Reference [25] Reference [84] Reference [120] Reference [132] Reference [139] Reference [156] Reference [157]

Table E.2 — Selected pollutant material interactions in enclosures significant to archives and library collections from BSI/PAS 198

Material	Pollutant	Damage	References
Lead-based pigments	Hydrogen sulfide	Formation of black spots	Reference [249]
Paper (cellulose)	Acetic acid (ethanoic acid) Volatile organic compounds (VOCs)	Increased brittleness, friability due to weakened structure	Reference [64] Reference [209]
Lead	Acetic acid (ethanoic acid) Formic acid (methanoic acid) Formaldehyde (methanol) Reduced sulfur gases	Transformation of lead metal to white salts; severe pitting and/or complete destruction of small collection items such as coins/tokens	Reference [250] Reference [248] Reference [251] Reference [242] Reference [62] Reference [252] Reference [73] Reference [89] Reference [111] Reference [253 Reference [254] Reference [255] Reference [214] Reference [216]

Table E.3 — Pollutant material interactions in open storage or display

Material	Pollutant	Damage	References
Colour photographs	Acetic acid Nitrogen dioxide Ozone	Fading, yellowing	Reference [37] Reference [72]
Lacquers	Dust	Change in visual appearance, mechanical damage due to cleaning	Reference [125]
Leather	Sulfur dioxide	Reduced mechanical properties (“red rot”)	Reference [202] Reference [212]
	Dust	Change in visual appearance, soiling, mechanical damage due to cleaning, increased rate of/providing catalyst for chemical degradation	Reference [125]
Natural organic colourants on paper	Ozone Nitrogen dioxide	Fading	Reference [82] Reference [192] Reference [225] Reference[226] Reference[227] Reference [229]

Table E.3 *(continued)*

Material	Pollutant	Damage	References
Paper and papyrus (cellulose)	Acetic acid Nitrogen dioxide Ozone Sulfur dioxide	Reduced mechanical properties, yellowing (especially of paper containing lignin)	Reference [36] Reference [101]
Pigments	Ozone	Fading	Reference [52]
Synthetic materials	Nitrogen dioxide	Yellowing	—
Textiles	Formaldehyde (methanol) Nitrogen oxides Sulfur dioxide	Reduced mechanical properties	Reference [36] Reference [104] Reference [161]
Textile dyes	Ozone Nitrogen dioxide	Fading	Reference [82] Reference [217]

Table E.4 — Approximate threshold concentrations for certain pollutant material interactions

Material	Pollutant and associated approximate threshold concentrations parts per billion by volume						
	Acetic acid (ethanoic acid)	Formic acid (methanoic acid)	Formaldehyde (methanol)	Reduced sulfides	Sulfur dioxide	Nitrous oxide	Ozone
Historic soda silicate glass	—	500	300	—	—	—	—
Limestone, ceramics, fossils, pottery	1 000	—	—	—	—	—	—
Shells, eggs	1 000	500	—		—	—	—
Lead	100	—	—	10	—	—	—
Copper	1 000	—	—	—	—	—	—
Silver	—	—	—	10	—	—	—
Zinc	—	—	—	10	—	—	—
Lead-based pigments	100	—	—	10	—	—	—
Paper	100	—	—	—	1	10	10

NOTE 1 Approximate threshold concentrations are given for those pollutant material interactions where thresholds have been published. Threshold concentrations have yet to be agreed for other materials such as textiles, plastics, organic colourants and leather, although most organic materials are susceptible to oxidising pollutants (e.g. ozone and NO_2) and acidic pollution (e.g. SO_2 and organic acids). In the absence of published threshold values, the values for paper is be used as approximate guidance.

NOTE 2 Further guidance on pollutants in collections environments is given in References [86], [88] and [211].

Annex F
(informative)

Interactions between temperature, RH, light and pollution

Examples of known interactions between the agents of deterioration covered in this document are shown in Table F.1.

Table F.1 — Examples of interactions between agents of deterioration

Interaction	Description
Temperature and RH	— Some materials react differently to the same temperature at different levels of RH, and vice versa, e.g. most hygroscopic materials.
Temperature and light	— Light energy will cause the surface temperature of collection items to rise. Some light-induced changes occur more rapidly at high temperatures. — Even in a moderately illuminated showcase, the surface temperature can rise 2 °C above the ambient. This in turn lowers the RH about 6 % in the boundary layer next to the collection items surface, leading to movement of moisture. — Direct sunlight, even through a glass window, can raise the surface temperature of a dark collection item over 60 °C, causing a very low surface RH. — Short periods of high temperature are often caused by direct sunlight or intense incandescent lighting, for example during filming. Some light-induced changes occur more rapidly at high temperatures.
Temperature and pollution	— Internally generated pollution increases with rising temperature because of an increased rate of decay of materials and diffusion of gases to the surface of materials.
RH and light	— High RH increases the speed of photo-activated degradation reactions in paper and many other materials.
RH and pollution	— RH increases the absorption of pollutants. High RH causes the water content of hydrophilic materials to increase and this facilitates absorption of most pollutants by such materials. — High RH causes deliquescence of water-soluble salts, which are common contaminants of collection materials. The aqueous medium allows ionization of absorbed gases, enabling them to react. — Low RH facilitates transfer of dust by electrostatic force, such as that caused by cleaning glass and plastic.

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