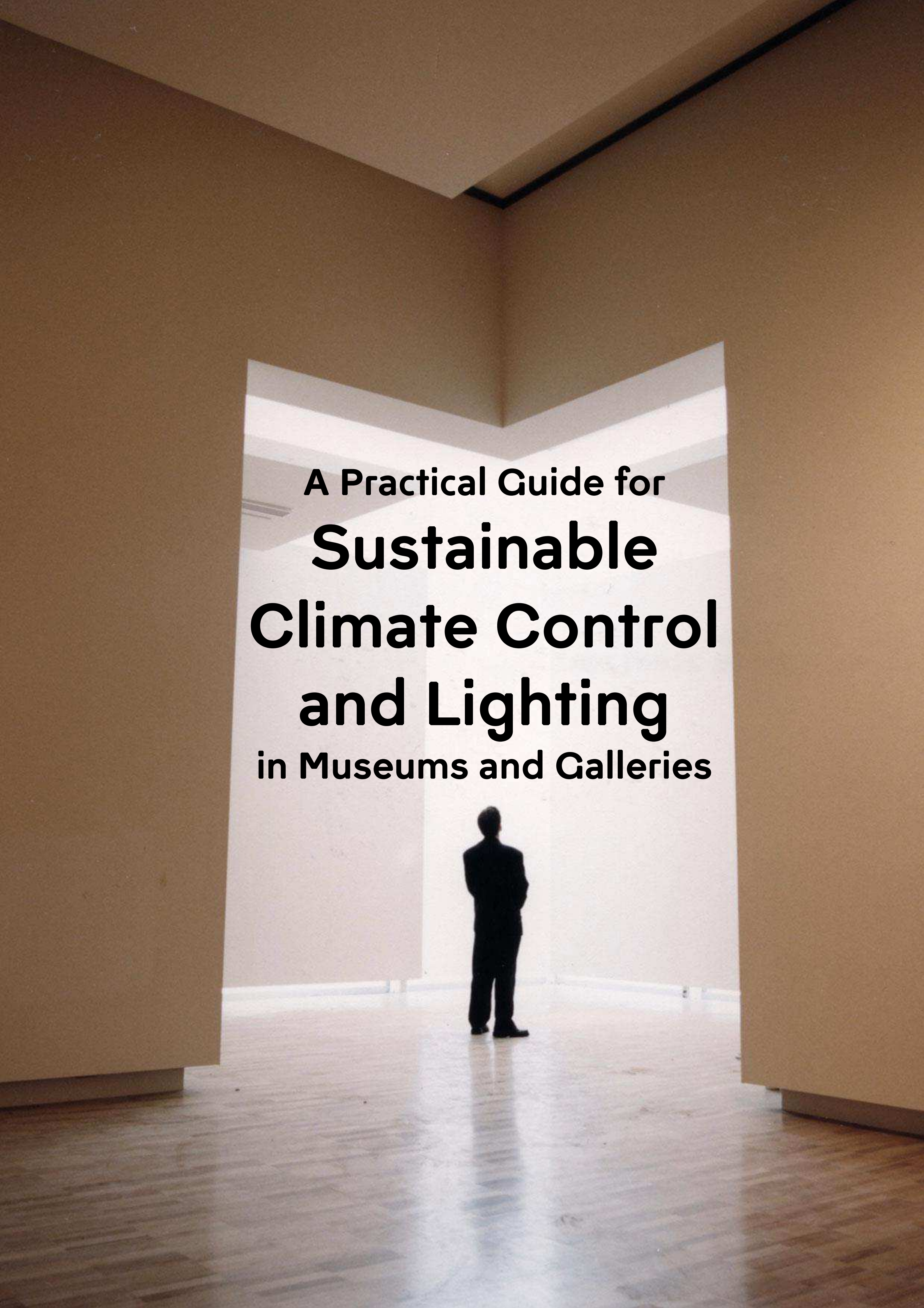
A Practical Guide for Sustainable Climate Control and Lighting in Museums and Galleries



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STEENSEN VARMING

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The views expressed herein are not necessarily the views of the Commonwealth of Australia and the Commonwealth does not accept responsibility for any information or advice contained herein.

This publication is primarily intended to provide guidance for facilities staff at museums, galleries, cultural and archival facilities. It is not intended to be exhaustive or definitive as the issues addressed continue to be a major topic of discussion and debate. It is recommended for users of this guide to exercise their own professional judgement and consult suitably qualified professionals when deciding whether to abide by or depart from it.

Foreword

Energy efficiency and sustainability are major issues in today's economically challenged climate. They are particularly relevant to our 'energy-hungry' museum and gallery sector.

Increasingly, museums and galleries are looking for ways to reduce their operating expenses and carbon footprint and improve their long-term sustainability by using appropriate technologies, products and systems.

In developing this practical web-based guide, our goal is to assist museums and galleries to make informed decisions around viable, economically and environmentally sustainable methods of exhibition practice and collections care.

A Practical Guide for Sustainable Climate Control and Lighting in Museums and Galleries is informed by national and international theory and practice. It embodies the collective intellectual work and experience of Steensen Varming, International Conservation Services and others working in this field. Many individuals have been involved in its production – in particular I acknowledge Emrah Baki Ulas, Julian Bickersteth and Fiona Tennant, for their countless hours, expertise and research in preparing this *Practical Guide* to assist the sector in moving towards sustainable lighting and environmental control systems and methodologies.

Our project partners, Museums & Galleries of New South Wales (M&G NSW), Regional and Public Galleries Association of New South Wales (RPG NSW) and Regional Galleries Association of Queensland (RGAQ), share Museums & Galleries Queensland's (M&G QLD) commitment to addressing the long-term sustainability of our sector – each has generously supported production of this resource.

Special thanks to Debbie Abraham, Director, Lake Macquarie City Art Gallery and former President of RPG NSW, for initiating the idea of commissioning the *Technical Industry Report: Museum and Gallery Lighting and Air Conditioning* (2011) and for encouraging M&G QLD to partner with RPG NSW on that project, leading to this further research.

I also acknowledge the financial assistance of the Australian Government through the Department of Industry and Science, and the Visual Arts and Craft Strategy, an initiative of the Australian, state and territory governments.

Museums and galleries engage audiences across generations, contributing long-term value to our communities through the preservation, research, interpretation and exhibition of historical and contemporary art, objects and stories. As such, they are well placed to advocate sustainable practices, foster a culture of environmental stewardship and champion green issues. By enhancing their own sustainability, museums and galleries are able to set a positive example, demonstrate leadership to their communities and effect positive change.

Rebekah Butler
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1.0 Introduction

Museums and galleries have seen many changes over the years. From their largely 18th Century beginnings as private collections of the rich, museums and galleries have shifted closer to the public sphere, becoming more democratic and pluralistic in nature. Throughout the 20th century the focus has shifted from being internally focused on collecting and conserving collections to an external perspective on presenting accessible collections, and creating places of mass attraction, discourse, attention and spectacle. Nowadays museums and galleries, as signature architecture, can become displays and attractors themselves, the success of which is mainly measured in terms of attendance figures, generated tourism and income. In this context, sustainability, and in particular appropriate climate control and lighting conditions have become a major topic of debate for museums and galleries.

The changing and evolving nature of museums and galleries has resulted in a wide spectrum of exhibition and spatial typologies over time. These range from historical manuscripts and ancient objects to organic specimens and fossils, from renaissance paintings to contemporary art and digital media. They are stored or exhibited temporarily or permanently in spaces that range from small to large, private to publicly owned, with building types of different complexities, with varying systems for climate control and lighting. As a result, the capital, operational and maintenance budgets of these facilities also present very diverse typologies that serve different objectives, priorities, organisational structures and processes.

In this era of sustainability and energy use, best-practice expectations for building systems are also rapidly evolving. Museum and gallery facilities are under increasing pressure to reduce their environmental impact and be run more efficiently, whilst the objective to provide the optimum environment for exhibition display continues to be the key interest. There are also opportunities for museums and galleries to benefit from government initiatives to improve their facilities in all aspects whilst addressing sustainability objectives.

With the above in mind, this document aims to form a practical guide for museums and galleries discussing available technologies, methodologies and key trends in climate control and lighting. It aims to assist museums and galleries in making informed decisions to improve their facilities to provide a more sustainable building environment, which holistically embraces and balances the necessities of visitor experience, collections care and energy performance.

This work is commissioned by Museums & Galleries Queensland in partnership with Museums and Galleries of New South Wales, Regional and Public Galleries Association of New South Wales and Regional Galleries Association of Queensland. It is intended primarily for the Australian reader. It is worth noting however that it is developed with many years collective experience in the museum and gallery sector covering locations all over the world and encompassing a wide range of climatic conditions. Acknowledging the macro and micro climatic issues to be considered, this Guide aims to strike the right balance in terms of providing practical suggestions for what are complex issues. While the technical issues discussed are of regular debate and should always be considered with specific regard to the local environment, this Guide also provides principles that are largely applicable, or at the least informative for most facilities globally.

1.1 How to Use This Guide

This Guide is designed to provide practical advice to museum and galleries on the planning, commissioning, operation or upgrading of climate control and lighting systems.

Differing levels of expert professional input may be needed depending on the type and size of the gallery or museum, and the extent to which changes are necessary to respond to sustainability goals. Sustainability initiatives should always be chosen to respond to those particular goals but also considering what the gallery or museum can practicably manage and afford.

The Guide includes a wide variety of options and strategies for museums and galleries to become more sustainable and a range of information to facilitate choices that can and will be appropriate to many situations. It does not intend however to preclude professional advice, rather it is developed to aid in identifying options suitable for your particular situation and in so doing, aid in developing a scope for and to act as a companion to professional services input.

The term "museum" within the Guide text, if used alone, implies both museums and galleries.

The term "collection" implies both owned collection and loaned items.

The Guide is composed in five main information sections:

Section 1 provides an introduction and outline of how to use this Guide.

Section 2 provides key background information on the museum environment including how damage is caused, and the consequences of a poor environment on collections and on the visitor experience.

Section 3 discusses the design considerations in selecting both an appropriate climate control and lighting systems.

Section 4 focuses on sustainable outcomes, and within this context details the relative merits and cost of a wide range of solutions that can be considered when seeking to resolve or improve climate control and lighting issues.

Section 5 provides a practical implementation plan for assessing a collection and building and a process to follow in moving towards more sustainable outcomes.

A bibliography and glossary is also provided at the end of the Guide.

2.0 Museum Environment

This section provides key background information on the museum environment including how damage is caused, and the consequences of a poor environment on collections and on the visitor experience.

In the design and operation of museum spaces and systems, a key requirement is to recognise conflicting environmental needs. A conservator needs to ensure that objects deteriorate as slowly as possible; exhibition curators and designers need to display objects with suitable effect and setting for maximising their interpretive value; the services engineer or designer needs to balance various needs to ensure all systems operate in accordance with the technical and budgetary constraints to meet the stated requirements for the repository. In smaller museums many of these roles may have to be combined and looked after with limited resources.

Whilst all this happens in the background, the visitor should be catered for, to view or experience the exhibits comfortably and clearly. An appropriate balance needs to be reached between these requirements, cost, and efficient system operation.

2.1 Environmental Damage to Collections

Deterioration of collections is inevitable, but the rate of change can be slowed so that its condition can be kept stable if the environment is properly managed.[1]

Environmental damage can occur in three primary ways:

- **Chemical**
  Chemical decay relates to changes in an object at a molecular level. Corrosion on metals, acid burning or staining, and embrittlement of paper or textiles are all examples of chemical damage. For organic material such as paper, vellum, wood, textiles and plastics, chemical decay is ongoing and spontaneous. Keeping items colder and drier often slows down the rate of chemical reactions.[2]

  Light induced damage (photodegradation) is also a form of chemical and irreversible damage where by light energy absorbed by the object causes decomposition of colours. Minimising overall light exposure and particularly ultraviolet and near ultraviolet parts of the light spectrum reduces the risk of light induced damage, whilst other parts of the light spectrum also need to be managed carefully.

- **Biological**
  Biological decay is caused by the attack of organisms such as mould and insects. This is most apparent in moist, hot environments. Organic materials are highly susceptible to this type of damage. Mould spores are always present in the atmosphere and just require a sustained high relative humidity for a certain period of time to propagate. Active mould produces enzymes that can digest organic materials such as paper and textiles, weakening or destroying them. Colourful blooms can also cause stains that cannot be removed. Generally, maintaining conditions below 65% relative humidity eliminates any risk from mould growth. Insect infestation, which can result in damage or loss due to feeding by insects or their larvae, is minimised by keeping relative humidity below 50% and by keeping space temperatures cool. Mould germination and its rate of growth are dependent on relative humidity, temperature, air movement, time, species of mould and the nutritious quality of the organic material. A

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[1] Image Permanence Institute. 2012. *IPI's Guide to: Sustainable Preservation Practices for managing storage environments.* IPI:New York. p10.
[2] Ibid. p11.

precautionary upper limit of 65% relative humidity at 20°C internal space temperature should minimise this risk, although at lower temperatures mould will take longer to germinate.[3]

- **Mechanical**
  Mechanical decay includes softening of plastics and waxes, cracking and buckling of wood, warping and delamination. This type of decay can be caused by physical force or mishandling, but can also be the result of changes in the environment that lead to physical stresses in an object. Environmentally induced mechanical decay is primarily driven by extremes of relative humidity, although temperature extremes can also affect the degree of risk if prevailing conditions are cold enough to cause brittleness or dry enough to cause cracking. Estimating the degree of risk of mechanical decay from improper humidity control within a space is difficult because the construction details of composite objects have a strong influence on their behaviour. Excessive dampness can result in differential expansion, sagging, warping and permanent deformation. Excessive dryness leads to contraction, brittleness, cracking and tearing. Risk also results from repeated fluctuations in moisture levels that cause a slow progression of micro-cracks and other forms of 'fatigue' in materials.[4]

2.2 Understanding Risks

An institution's decision to exhibit an object may mean that its future usable life is compromised to some degree. It is therefore crucial to understand the effect environmental parameters have on exhibited items. Environmental conditions should be created, designed and operated to minimise any detrimental impact on the object, whilst providing adequate conditions to ensure a worthwhile visitor experience.

Precautions to prevent damage through shock and vibrations, human intervention, vandalism or theft are crucial in providing a broad exhibition environment that minimises the risks to collections. In addition to these, the museum environment may present less noticeable and often cumulative and long-term risks such as degradation related to climate conditions and light exposure. In order to manage these, building systems need to be designed and operated with conservation requirements in mind.

The preservation quality of an environment is best judged in terms of relative risks and benefits to the collection in the space. Decay occurs through different mechanisms; chemical, mechanical and biological, as spelt out in section 2.1 above. Conditions that bring benefits for one decay mechanism may bring increased risk with another. For example, extreme dryness may eliminate corrosion risk in metals but for some objects, such as vellum-bound books, dryness presents a high risk of shrinkage and brittleness. The right balance of risk and benefit needs to be found.[5]

In order to know how to care for a collection, the first thing is to understand the different material types within it, as this will dictate the conditions to achieve and the environmental risks to avoid. Broadly speaking inorganic material (i.e. objects not made from living matter, such as stone and metal) are more robust and cope better with exposure to environmental extremes than organic material (i.e. objects made from living matter, such as furniture and textiles). Many objects are composite (made from more than one material, e.g. ivory buttons on an Asian textile), in which case the most sensitive or vulnerable material present is the key one to consider.

[3] Ibid. p11.
[4] Ibid. p11.
[5] Image Permanence Institute. 2012. *IPI's Guide to: Sustainable Preservation Practices for managing storage environments.* IPI:New York. p12.

2.2.1 Temperature and Humidity Related Damage

Temperature and humidity are the two key measures of environmental control. They are directly linked, which is why they are typically spoken about together. The dew point (the temperature at which water vapour turns to liquid), determines what combinations of temperature and relative humidity are possible. At a constant dew point, the temperature goes up when the relative humidity goes down and vice versa.[6]

Generally, relative humidity is of more concern in gallery spaces, as damage from poorly controlled humidity levels is seen faster. Detrimental effects of inappropriate temperature control are generally slower to visually detect.

At high temperatures, chemical reactions increase and the rate of natural ageing increases. Biological activity will also increase. At higher room temperatures insects will generally eat more and breed faster. Mould can also grow faster within certain temperature ranges. A practical approximation for organic materials is that reaction rates double with each 5°C temperature rise.[7] This is why colder temperatures are often recommended for some collection materials.

The following list explains why damage can occur to objects in spaces with poor temperature control:

- Some materials are sensitive to low temperatures, particularly polymers found in modern paints and coatings, rubber and plastic objects. Temperatures that are too low can potentially cause desiccation resulting in fractures in paints, adhesives and other polymers.
- Wide and frequent fluctuations in temperature can cause fractures and delamination in brittle, solid materials. Furniture, ivory, and oil paintings are particularly vulnerable.
- Sustained high temperatures have a much more significant impact on the stability of collection materials than do temporary spikes or wide fluctuations of temperature.

Relative humidity is a description of how saturated the air is with water, i.e. how humid the air is relative to how much it could be when it is 100% saturated with water. Water vapour affects collections as it forces its way in and out of materials. Only organic materials that naturally contain water are susceptible to moisture movement. These materials absorb or release water to equilibrate with the relative humidity of the surrounding environment. When they do this, they can swell or shrink and change shape, which over time can cause damage. As the relative humidity in the space increases, objects absorb more water, as it decreases they release moisture, thus causing dimensional movement.

However, non-absorbent material like metal can still be affected by moisture in the air and corrode.

High relative humidity can result in mould, metal corrosion and dye bleed in vulnerable collections, as well as swelling and warping of wood and ivory, buckling of paper, stiffening, cracking and flaking of leather and photo emulsions, softening of adhesives, and an increase in biological activity.

At the other end of the spectrum, low relative humidity will cause organic materials to shrink, warp and crack, and papers and textiles to become brittle.

Fluctuating relative humidity will shrink and swell unconstrained organic materials, and crush or fracture constrained organic materials because layered organic materials tend to delaminate and/or buckle and loosen joints in organic components. It takes time for susceptible material to react to changes in relative

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[6] Ibid. p8

[7] British Standards Institute. 2012. *PAS198:2012 Specification for managing environmental conditions for cultural collections.* BSI Standards Limited: London. p6.

humidity, so sudden or short-term relative humidity fluctuations do not affect the moisture content of objects immediately. Periods of sustained high humidity or low humidity are much more harmful.

Dew point control is important in minimising the risk of condensation developing within a space. This should not be a major concern in tightly controlled exhibition spaces as the dew point should never be reached. However, it can become an issue in spaces with relaxed set-points during certain external conditions. Implementing a suitable control strategy can minimise this risk. Details of this strategy are outlined later in this Guide.

2.2.2 Indoor Air Quality and Pollutant Damage

Airborne dust, as well as chemical pollutants, can damage collections. Pollutants including ozone, nitrogen oxides, sulphur dioxide and dust are the biggest concerns. [8]

The sources of pollutants are various and include acetic acid off-gassing from paints and exhibition display materials, formaldehyde from plywood panels, and sulphur dioxide from new carpet underlay. Objects themselves can in certain instances be the cause of pollutants, especially cellulose acetate and cellulose nitrate items and photographs.

The damage caused by pollutants includes: corrosion of copper, silver and lead objects, brittleness in paper-based objects and the breakdown of glazes on ceramics.

Some collection materials generate pollutants as they degrade, e.g. cellulose nitrate film, some rubbers, resins and wood. These materials should be monitored and isolated from other sensitive material.[9]

Dust is a particular concern as it can hold chemicals and thus damage surfaces on which it lies. Dust can also be a source of nutrients for insects and mould.

The environment in which pollutants and dust are allowed to accumulate has a direct effect on the damage they can cause, with pollutant interaction and chemical reactions increasing with higher temperature and relative humidity levels. This damage can be cumulative and irreversible.

Levels of dust and indoor pollutants therefore need to be monitored and limited as far as possible, and collection items deemed to be particularly at risk placed in a less polluted environment.

2.2.3 Light Induced Damage

Both visible light and ultraviolet (UV) radiation may cause damage to collections resulting in the fading of pigments and breakdown of materials at molecular level, causing degradation. Light can also cause chemical change, for example inks, dyes and pigments will discolour; or physical changes, for example, mechanical strength can be lost or glossy materials become matt. Light induced damage often occurs over a long period of time. This fading and degradation of materials due to light exposure is described as photodegradation.

Photodegradation is a chemical process whereby the molecules decompose through the absorption of energy in the form of photons, particularly from the ultraviolet and visible parts of the electromagnetic spectrum. As a result of photodegradation, material composition breaks up and becomes transformed.

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[8] British Standards Institute. 2012. *PAS198:2012 Specification for managing environmental conditions for cultural collections.* BSI Standards Limited:London. p14.
[9] Ibid. p15

When photodegradation takes place on molecules carrying pigmentation that gives an exhibition object its colour, the pigments can lose their chemical composition and the colour quality may shift or weaken. Photodegradation is an irreversible process, whereby it is impossible to create or repair the lost information on an exhibition object through interventive methods. Organic materials are usually more sensitive than inorganic materials. Some materials are very sensitive, some only slightly sensitive to light and some are not sensitive at all. As the wavelength of radiation decreases, the rate of photochemical damage generally increases. Light and UV radiation damage is cumulative and proportional to exposure. Damage can be minimised by reducing either the illuminance or the duration of exposure, or both.

International Commission on Illumination (CIE) Technical Report 157:2004 forms the basis of most modern industry guidelines for conservation to prevent or minimise light induced damage on collections. These guidelines categorise different types of exhibition materials and objects and recommend cumulative kiloluxhours/year exposure limits depending on their light sensitivity. Current lighting guidelines for conservation are however based on the nature of the light that is emitted by incandescent light sources. The composition of the visible light and the UV output from incandescent sources is very different to that of modern museum lighting sources. As new lighting technologies, such as the Light Emitting Diode (LED), are becoming the primary source of electric illumination in exhibition display lighting, the lighting intensity and exposure limits for conservation need to be re-evaluated and most lighting conservation guidelines of today need to incorporate amendments to suit the characteristics of these new light sources.

In relation to this, the conservation profession is also currently grappling with both the technology of how to measure light damage, and also the language by which to describe it. Traditional methods of light damage measurement such as the Blue Wool scale (a textiles industry measure of light fastness) are now hard to source. New technologies such as micro fading (where high volumes of light are applied to a microdot to assess rate and extent of fading) are expensive to access. The language required to describe fading has been helped by the development of the Just Noticeable Fade (JNF) index whereby the gradations between full colour and full fading is identified in a series of steps, along with the kiloluxhours of light exposure (the generally accepted unit for light exposure in exhibition display) to cause this to happen. This then allows curators to decide how to ration the maximum acceptable kiloluxhours of exposure to cause 1 JNF to occur, e.g. if 1 JNF for an object requires 10,000 kiloluxhours, and the museum has a policy of allowing 1 JNF to occur every 25 years, then the curator can choose how to manage the lighting conservation issue by balancing the duration and the frequency of the display as well as the light levels to ensure that the total amount of exposure on the object over a duration of 25 years does not exceed 10,000 kiloluxhours.

2.3 Ensuring Visitor Comfort

It is important to remember that the business of many institutions is to display and interpret collections to the public and that therefore it is essential to consider the visitor experience as well as preservation of collections when reaching decisions on the level of climate control and lighting.

Human thermal comfort is defined as condition of mind that expresses satisfaction with the thermal environment. Due to individual differences, it is impossible to provide a thermal environment that will satisfy everybody. As such, there will always be a percentage of dissatisfied staff and visitors. The aim therefore is to provide an environment that delivers a low level of occupant discomfort/dissatisfaction. The Chartered Institute of Building Services Engineers (CIBSE) has extensive information on human thermal comfort. There are many factors such as air movement, mean radiant temperature, activity and clothing levels that impact human thermal comfort. This Guide mainly focuses on temperature and relative humidity.

The following diagram shows the relationship between temperature and relative humidity on human thermal comfort. Also included within this diagram is a representation of recommended set point parameters. As shown, there are some areas that are within the occupancy comfort limits that would fall outside gallery collection limits and vice versa. Therefore, a case-by-case assessment is required to ensure there is an appropriate balance between occupant comfort, energy efficiency and collection safety. The vulnerability of the collection to decay from the surrounding environment will be a large factor when deciding on the appropriate environmental control set points. Institutions need to determine as to whether they allow exhibition spaces to be set to these parameters, balancing visitor comfort, energy efficiency and collection care.

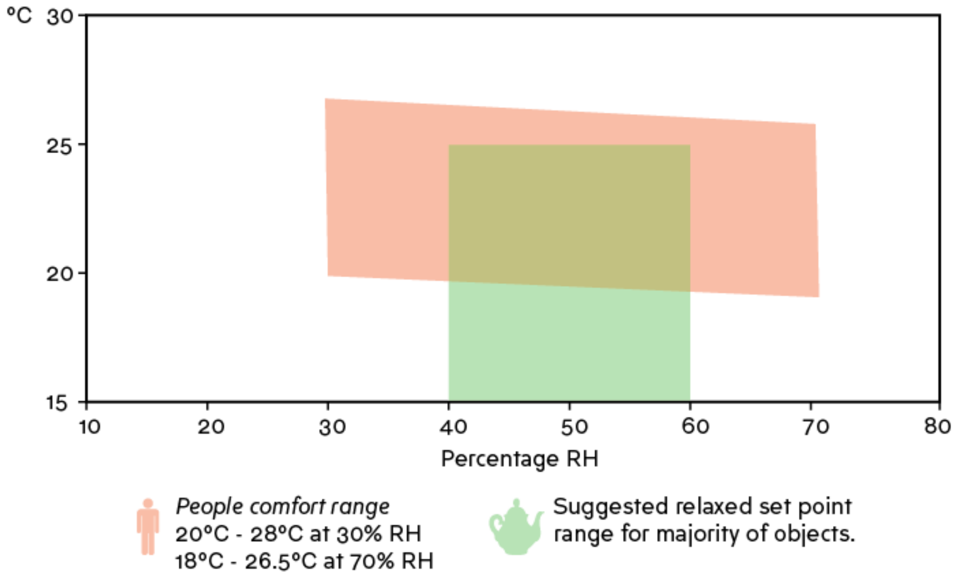

Figure 1: Human Comfort/Object Conservation Parameter Comparison
(Adopted from a figure included in The Museum Environment (Thompson, 1978) to reflect recommended set point range for majority of objects)

Often there are large areas in gallery/museum buildings such as function rooms, education areas and offices that do not require a tightly controlled environment. These areas lend themselves to a more relaxed approach to air conditioning and ventilation in comparison to exhibition or storage spaces. Different system approaches should be employed in these areas to better suit the nature of these spaces and their uses.

Visual performance and comfort is also a key consideration that needs to be attained through careful lighting design. Light adaptation and dark adaptation within a space and during the transition from one space to another is a key factor to enable the visitor to view the exhibits well, and be able to safely and comfortably circulate within the spaces. Extreme contrast and glare within any field of view, should be avoided.

Where it is possible and practical to utilise natural daylight, it can enhance the museum space visually, contribute to sustainability goals and support visitor experience through health and wellbeing benefits.

3.0 Design Considerations and Methodologies

This section discusses the design considerations in selecting appropriate climate control and lighting systems.

There are a large number of parameters and conditions that design professionals need to understand and control when undertaking working in gallery and museums environments. It is critical that a common language is used to discuss these, so that all parties can agree on the extent to which they need to be controlled.

3.1 Climate Control Design Considerations

3.1.1 External Conditions

External conditions have a dramatic effect on the internal environments of galleries and museums. Extreme external temperatures and humidity levels can damage collections if measures are not in place to buffer the internal space from these harsh external conditions. Depending on the vulnerability and value of various collections, full climate control may not be required and there are a number of simple and cost effective strategies that galleries and museums can implement to help protect collections from damaging external conditions in lieu of implementing full climate control. It is incumbent on each institution to undertake an assessment to determine whether entirely passive control will suffice or whether help from active mechanical systems will indeed be necessary.

This document focuses largely on the most sustainable way of delivering controlled internal conditions when climate control systems are in place. Even when this is the case however, there are typically a number of passive initiatives that should always be considered to reduce reliance on these systems.

The thermal mass and hygroscopic capacity of building in its walls, floor and roof acts as a buffer between the internal environment and external temperature and humidity fluctuations. The addition of ceiling and wall insulation (in the right place in composite constructions) will reduce the impact that external conditions have on the internal environment. Simple measures like ensuring all doors and windows are kept shut on cold days will help retain heat within the building. Ensuring there are effective seals on all doors and windows when closed also has a significant benefit on maintaining the indoor environment, as well as limiting the opportunity for dust and other pollutants to enter the space. Placing blinds and curtains on windows and closing them when required will reduce heat gains within a space caused by direct sunlight, as well as creating more stable temperature and humidity conditions within the space.

Planting deciduous trees that shade the north and west facing walls of the museum or gallery in summer will minimise heat gains through those walls during hot periods. In winter these plants drop their leaves and allow the sun to warm the north and west facing walls. This will reduce heat loss through those walls during cold periods. In both cases it will enable more stable conditions within the space. Awnings and additional solar shading could also be used if plants are deemed inappropriate for the building.

Passive control techniques should always form part of wider sustainability strategies for galleries and museums. The above provides a few examples only - there are many more that may be applicable, particularly in the case of new build facilities and a thorough review of passive initiatives should always be undertaken at the very early planning stages of the project. This section of the guide is largely targeted at existing facilities that already have some active climate control system in place.

3.1.2 Internal Considerations

As the Image Permanence Institute notes, "We're now concerned much more with what poses the greatest threat (that is, in identifying the circumstances we need to avoid) than we are with articulating an ideal".[10]

The environmental standards that museums/galleries world-wide have largely adhered to over the last fifty years were developed after the Second World War to provide the optimum conditions for collection care balanced with visitor comfort. Critical to them was the creation of a stable environment around 20°C and 50% relative humidity.

As awareness of climate change and the significant impact that human activity has upon it has increased, so too has the focus and desire to reduce the amount of energy used by climate control systems in maintaining these 'optimum' conditions. It is fair to say that the conservation community is currently divided about the issue. Some maintain that giving up the present environmental standards would entail an increased risk to cultural heritage and should not be entered into prematurely without strong scientific evidence, whilst others believe the standards are not ideal for all circumstances, do not meet the needs of many collection types, and are difficult and costly to maintain mechanically.

For the moment it is clear that there is no such thing as a 'one size fits all' or a 'straight line' environmental standard that is easily attainable, appropriate for preservation of mixed collections, or environmentally sustainable. The new UK standard Publicly Available Specifications (PAS) 198 'Specifications for Managing Environmental Conditions for Cultural Collections' is a tool to help collection managers establish and maintain environmental conditions based on an understanding of their collection materials' vulnerabilities to agents of deterioration, the local climate, the capabilities of the mechanical system and the building envelope, and the move toward energy reduction.

As PAS 198 spells out, there needs to be a move "to a more mutual understanding of the real conservation needs of different categories of object, which have widely different requirements and may have been exposed to very different environmental conditions in the past".

3.1.2.1 International Position on Environmental standards

The Australian Institute for Conservation of Cultural Material (AICCM) set up a taskforce in 2009 to attempt to provide Australian collection managers with guidelines as to how to provide a safe, yet greater allowable range of conditions, which will suit the majority of material types found in collections. AICCM's *Interim Temperature and Relative Humidity Guidelines for Acceptable Storage and Display Conditions* are as follows:

- Temperature – typically between 15-25°C with allowable fluctuations of +/-4°C per 24 hours;
- Relative humidity – typically between 45-55% with an allowable fluctuation of +/-5% per 24 hours;
- Where storage and display environments experience seasonal drift, relative humidity change to be managed gradually across a wider range limited to 40-60% to minimise stress on collection items.

These are for general collection material based on guidelines developed by professional conservation groups internationally, most notably by the American Institute for Conservation (AIC).

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[10] Image Permanence Institute. 2012. *IPI's Guide to: Sustainable Preservation Practices for managing storage environments.* IPI: New York. p5.

<u>The AICCM recommended Interim Temperature and Relative Humidity Guidelines for acceptable storage and display conditions of general collection material are:</u>

Temperature – between 15–25°C with allowable fluctuations of +/-4°C per 24 hr

Relative Humidity – between 45-55% with an allowable fluctuation of +/-5% per 24 hr

Where storage and display environments experience seasonal drift, RH change to be managed gradually across a wider range limited to 40% – 60%

Temperature and Relative Humidity parameters for preservation of cultural materials will differ according to their material, construction and condition, but stable conditions maintained within the parameters above are generally acceptable for most objects.

AIC Interim Guidelines endorsed by the Association of Art Museum Directors:
For the majority of cultural materials, a set point in the range of 45-55% relative humidity with an allowable drift of +/-5%, yielding a total annual range of 40% minimum to 60% maximum and a temperature range of 59-77°F (15-25°C), is acceptable.
•Fluctuations must be minimized.
•Some cultural materials require different environmental conditions for their preservation.
•Loan requirements for all objects should be determined in consultation with conservation professionals.

Further discussion was held at two major international conservation conferences in September 2014, the ICOM–CC (Committee for Conservation) Conference in Melbourne and the IIC (International Institute for Conservation) Congress in Hong Kong. As a result of these discussions the following declaration was published:

Environmental Guidelines – IIC and ICOM-CC Declaration

At the IIC congress in Hong Kong and the ICOM-CC conference in Melbourne in September 2014 the delegates discussed and agreed the following declaration:

The conservation profession has come together and agreed a position on environmental guidelines as follows:

<u>*Sustainability and management*</u>

•The issue of museum sustainability is much broader than the discussion on environmental standards, and needs to be a key underlying criterion of future principles.
•Museums and collecting institutions should seek to reduce their carbon footprint and environmental impact to mitigate climate change, by reducing their energy use and examining alternative renewable energy sources.
•Care of collections should be achieved in a way that does not assume air conditioning (HVAC). Passive methods, simple technology that is easy to maintain, air circulation and lower energy solutions should be considered.
•Risk management should be embedded in museum management processes.
Museum environment
•It is acknowledged that the issue of collection and material environmental requirements is complex, and conservators/conservation scientists should actively seek to explain and unpack these complexities.
•Guidelines for environmental conditions for permanent display and storage should be achievable for the local climate.

<u>*Loans*</u>

•There needs to be transparency about actual environmental conditions achieved in museums to ensure that realistic requirements are made for loan conditions.
•Noting that most museums in the world have no climate control systems in their exhibition and storage spaces, we acknowledge the need for a document that will influence decision makers that the environmental conditions for international loans may not be appropriate for the permanent display and storage of collections in all museums.
•There needs to be flexibility in the provision of environmental conditions for loans from museums which have climatic conditions different from the set points in the guidelines. This may be achieved with alternative strategies such as microclimates.
Existing guidelines
•The existing interim guidelines agreed by AIC, AICCM, the Bizot group etc (see Appendix) should be guidelines not interim guidelines. It is noted that these guidelines are intended for international loan exhibitions.

Bizot Interim Guidelines for Hygroscopic Materials

For many classes of object[s] containing hygroscopic material (such as canvas paintings, textiles, ethnographic objects or animal glue) a stable relative humidity (RH) is required in the range of 40–60% and a stable temperature in the range 16–25°C with fluctuations of no more than ±10% RH per 24 hours within this range.

More sensitive objects will require specific and tighter RH control, depending on the materials, condition, and history of the work of art. A conservator's evaluation is essential in establishing the appropriate environmental conditions for works of art requested for loan.

3.1.3 Specific Temperature and Humidity Control Set Points

Specific temperature and relative humidity requirements for sensitive or fragile collections should be determined in consultation with a professional conservator. Some material will require different or tighter control of internal space conditions. These types of areas can be managed through the use of micro-climates. Additional specific environmental requirements such as light levels, air-flow, and other conditions should be determined based upon professional conservation advice.

In addition to the above, organisations that intend to borrow items may need the capacity to modify their display environments to cater to the needs of the loaned material.

The most appropriate environment for a collection requires an understanding of:

- The material types in the collection (organic, inorganic, composite materials);
- The aspects of the environment that affect collection material (temperature, relative humidity and dew point); and
- The basic modes of deterioration (chemical, biological, mechanical).

3.1.4 Rate of change

As previously mentioned, water vapour affects collections as it forces its way in and out of materials. For this reason ensuring stable humidity levels within a space is critical. For most collections, i.e. collections with no specific relative humidity requirements, museums should limit humidity level fluctuations of no more than +/-5% per 24 hours and temperature fluctuations of no more than +/-4°C per 24 hours. For museums that utilise seasonal adjustments to save energy, adjustments should be made very slowly over a number of days to ensure conditions within the space do not fluctuate outside of the above limits.

3.1.5 Seasonal Adjustment

Any review of internal environmental set points must be considered in conjunction with a seasonal adjustment strategy in order to realise maximum energy savings. This will allow the set points to be closer to the ambient external conditions, and thus ensure the climate control system uses less energy converting external air to internal conditions, whilst still remaining within overall acceptable parameters.

Set points must therefore be tied in to local climatic conditions and manoeuvred over the seasons to suit local seasonal weather data. See Section 3.2.10 for more details on establishment of set points for seasonal adjustment, and Section 5.2.4 for recommended levels.

3.2 Climate Control Methodologies

Once environmental setpoints have been investigated and relaxed as far as practicable and passive control measures investigated and applied (See Section 4), there may still be a need to employ active mechanical systems in some areas to ensure collections are adequately protected. Where this is the case the following issues should be taken into account.

3.2.1 Ventilation

Minimise outside air quantities as far as possible whilst taking account of statutory requirements for occupants and pressurisation requirements. On larger systems consider **dedicated outside air units** that supply the required quantity of outside air onto recirculation units serving gallery/museum spaces at a set temperature and humidity. With this approach, the recirculation units will not be subject to the constant fluctuations of the outside air thereby aiding stable control of internal space conditions.

3.2.2 Materials

Where appropriate, minimise the use of building materials which 'offgas', or release contaminants that have a detrimental effect on the internal air quality. Contaminants include Volatile Organic Compounds (VOCs), chemicals and dust.

As part of a wider sustainability strategy, there should be a materials management plan in place from design through to operation of the building, to recycle and reuse materials wherever possible from construction through to deconstruction, and to source materials to minimise transportation distances.

3.2.3 Plant Selection

Before selecting climate control plant or equipment, it is useful to have a clear understanding of your needs, both now and into the future. If mechanical climate control is deemed to be essential, incorporate as many passive initiatives as practicable/possible into the (design and then consider the following questions:

- Identify **budget** – both capital and ongoing operational funds available (i.e. make the plant suit the budget not the other way around).
- Identify the **lifecycle** of the plant. How long will you need it to last?
- Identify access to **maintenance** companies and expertise – are local companies able to service the plant you want?
- Understand your **local climate** – get information on both Humidity and Temperature levels for the whole year – so you can establish realistic set points.
- What materials do you have in your collection? What conditions do they

require?

- Identify the **Relative Humidity and Temperature Conditions** you need to maintain in all collection areas. Can these areas be zoned?
- Understand the capability and needs of your **Building.** How will the building material cope with the internal conditions you want to achieve?

After exhausting all efforts to maximise passive performance of a building, the following active system considerations should be noted.

3.2.4 Cooling and Dehumidification

- Use **chilled water systems** for cooling where possible as these systems enable stable off coil air temperatures and therefore stable temperature and humidity control. Ensure chillers are capable of providing chilled water at consistent supply temperatures (typically 6°C where dehumidification is necessary) both at peak load and across the entire part load range of operation. It is common to see oversized chillers that lock out in mid seasons because compressors are starting/stopping too frequently, therefore leading to a rise in system chilled water temperature and a subsequent loss of space conditions. Consider **variable speed compressors** or **chilled water storage/buffer vessels** as well as dedicated **low load chillers** on larger systems.
- If **Direct Expansion (DX) systems** are to be used, ensure they are specifically manufactured for close control applications. Most DX systems are designed for comfort provision rather than close control and are not appropriate for maintaining stable internal design conditions (particularly in terms of RH control).
- Avoid the use of standalone dehumidification equipment as a permanent solution. All dehumidification equipment should be effectively and efficiently drained, with drains located outside of exhibition or storage areas.
- **Desiccant dehumidification** systems may be appropriate as an energy efficient means of removing moisture from outside air in larger systems in humid climates and therefore taking load off the chilled water system Fine dehumidification control will likely still be necessary via chilled water coils. Dessicant systems are particularly economically viable where a waste heat source exists to regenerate the desiccant medium (e.g. waste heat from onsite electricity generation – cogeneration or trigeneration systems).
- **Face and Bypass** arrangements around AHU (Air Handling Unit) chilled water cooling coils should be considered where physical space is available within AHU plant rooms so to remove (or significantly reduce) the requirement to reheat air back up to supply temperatures after it has been overcooled for dehumidification purposes.
- **Dew Point control** strategies should be employed for space and supply set points rather than looking at temperature and humidity as separate parameters for control logic in order to avoid equipment potentially fighting against itself and therefore operating inefficiently
- **In dehumidification mode,** supply air into a space at a constant dew point condition to match the space set point (rather than supplying at a lower dew point – which equates to drier air). With this approach the changeover of air in the space is relied on to get the space down to the required humidity set point and this approach aids in ensuring rate of change requirements are adhered to (experience has shown that supplying air into the space that is drier than the space set point condition consistently results in rapid dehumidification gradients that can be damaging to collections). Provide an **off coil temperature sensor** for this purpose – immediately downstream of the cooling coil, the dry bulb temperature approximates the dew point temperature of the air and therefore a single sensor can be used to control the supply air dew point condition rather than having to use both a temp and relative humidity sensor whose combined readings are inputted into a dew

point calculation. If there is insufficient space after the cooling coil for a sensor, both a temperature and relative humidity sensor will be necessary in the supply ductwork downstream of the supply fan. See also section 3.2.10

3.2.5 Heating

- Use **hydronic (Low Temperature Hot Water or Medium Temperature Hot Water) heating systems** where possible (i.e. hot water from a boiler or other heat source). Water-based systems enable good controllability if appropriately designed and should therefore result in much more stable temperatures within critical spaces. In most instances, gas-fired boilers result in significantly lower carbon emissions than electricity generated by coal-fired power plants, particularly when transmission losses are taken into account. Gas is also currently cheaper than electricity.
- If **electric heating** systems must be used, ensure they are thermistor controlled (i.e. have infinitely variable rather than stepped control) so as to ensure more stable conditions.

3.2.6 Humidification

- Consider **ultrasonic humidification** where possible as this technology atomises water into the air stream rather than boiling it and is therefore more efficient. Ultrasonic technology does however require special water treatment (typically Reverse Osmosis [RO] plus associated pre-treatment) and whilst small package RO systems are available, this technology may not be appropriate in all instances (e.g. where local expertise is not available to maintain such systems).
- In this case, **infinitely variable steam humidification** (electrode steam generation) is an acceptable approach and can provide precise, stable control.
- Avoid **spray humidification** systems as they are inefficient (requires over humidification and then dehumidification down to required supply condition) as well as being a relatively unclean approach that can have issues with legionella etc.

3.2.7 Maintenance

System design must allow for ongoing operation and maintenance requirements of the installed systems and the envisaged skill and frequency of facility management that will be available. It is recommended that design teams liaise with facilities managers towards selecting the most appropriate level of system complexity and reliability.

Planned Preventative Maintenance (PPM) of any installed systems is also recommended to aid efficient operation and prevent the failure of plant, and therefore loss of service to museum and gallery spaces.

Investing in a schedule of planned maintenance measures, minimises disruption and unexpected costs, and represents an effective way of increasing the reliability and lifetime of the installed systems.

3.2.8 Control Levels

A client can procure the best museum/gallery building possible and fit it out with the most appropriate active systems to maintain environmental parameters (whatever they may be) but this can all be undone by inappropriate or poorly executed control strategies. It is essential to employ strategies that are specific to museum and gallery applications and not strategies that are intended for more comfort-based applications.

Once appropriate parameters have been set by conservators for a particular project, the following issues should also be taken into consideration:

3.2.9 Set Point Seasonal Adjustments

Research into how different materials react to different environmental set points has been carried out by a number of sources over the years. In 1994, the Smithsonian Institution's Conservation Analytical Laboratory issued revised guidelines allowing for as much as 15% fluctuation in relative humidity, and fluctuations by as much as 10°C. Other research has come to the same conclusion.

As noted previously, the 'typical' set point parameters are particularly onerous in terms of energy, and industry studies suggest that they do not seem necessary to protect a large portion of collection items. There is therefore scope to widen the set point parameters in order to achieve a more energy efficient outcome.

The set point chosen must be appropriate to the particular climatic conditions of a particular institution with the rule of thumb being that the set point should be as close as possible to average climatic conditions in order to be as energy efficient as possible. As climatic conditions alter throughout the year so the internal set points should be shifted to suit (within the aforementioned parameters) – this is known as a seasonal adjustment strategy. Seasonally adjusting temperature and humidity (or dew point) set points according to ambient temperature profiles is a low risk opportunity for energy savings in terms of due care to collections.

If local ambient conditions are appropriate, the maximum variance in set points suggested for seasonal adjustment (for most collection types that are in good condition) are as follows:

- 20°C +/-5°C (i.e. the space set point can be anywhere from 15° C to 25°C with short fluctuations around this set point as set out in the following section).
- 50% relative humidity +/-10% relative humidity (i.e. the space set point can be anywhere from 40% to 60% relative humidity with short fluctuations around this set point as set out in the following section).

These widened parameters represent the range that a majority of materials can be kept without significant deterioration. It does not mean that the conditions of spaces within which collections are kept can be constantly changing within these parameters; rather it means that constant set points within this range can be chosen and maintained at different times of year.

With reference to *ASHRAE Handbook 2011,* Chapter 23: Museums, Galleries, Archives and Libraries, the suggested parameters fall somewhere between Class 'A' and Class 'B' standard of control detailed (see Table 9), when considered in conjunction with the previous rate of change, section 3.1.4, of this Guide.

It is also highlighted that the Victoria and Albert Museum, UK, and the Smithsonian Institution, USA, have recently moved to working within a relative humidity range of 35% to 70% for large portions of their collection.

Note: The collecting organisation needs to be ultimately responsible for defining permissible ranges of temperature and humidity. These bands are provided as suggestions only based upon interpretation of existing published information and experience gained through long-term interaction with the museum and gallery sector.

3.2.10 Dew Point Control

Generally, air handling systems activate and deactivate humidification and dehumidification modes based on the detected deviation from the relative humidity set point of the air within a museum or gallery space. Although controlling to a relative humidity and dry bulb temperature in theory results in stable conditions, in reality relative humidity is difficult to make uniform throughout a space or building and so control comes at a running cost. Changes in dry bulb temperature across a room means that relative humidity varies widely throughout a building (remember that RH is a function of temperature rather than an absolute), which makes the air conditioning system constantly 'hunt' to achieve control within a defined range of relative humidity.

In contrast, when the temperature/relative humidity signal is converted to dew point and used as the control value, the system will not be hunting up and down as sensible loads change in the space. The absolute humidity will stay near constant, so the system as a whole will operate in a more stable manner.

For example, in a museum or gallery space with high ceilings and a ceiling supply system, it may be quite common to have a dry bulb temperature difference between the floor and ceiling (higher relative humidity at low level due to 'cooler' air and vice versa for the ceiling) potentially creating conflicting relative humidity readings in the space and unnecessary calls for dehumidification and humidification. In addition to this, as another example – if a large group of patrons congregate in a concentrated area of the gallery, creating a heat gain and thus rise in dry bulb temperature in the space, the system will read a drop in RH and call for the system to add moisture to the supply air. In these cases, under dew point control, the dew point temperature (or moisture content) in the space would be relatively stable and would have only a requirement for sensible heating or cooling.

The table below shows the changes in relative humidity as a function of the changes in dry bulb temperature at fixed moisture content of 11.1°C which would be the dew point temperature of air at 22°C / 50% relative humidity.

Dry Bulb Temperature (°C)	Relative Humidity (%)	Moisture Content (g/kg)	Dew-point Temperature (°C)	Current Mode of Operation
24.0	**44.3**	8.26	11.11	Humidification
23.0	**47.0**	8.26	11.11	Humidification
22.0	**50.0**	8.26	11.11	Normal
21.0	**53.1**	8.26	11.11	De-hum
20.0	**56.5**	8.26	11.11	De-hum

Table 1: Internal conditions of constant dew point and moisture content, with varying relative humidity

The above table shows that humidity control strategies that respond to RH sensors only, the system could be unnecessarily in humidification and dehumidification mode at a satisfactory moisture content condition. This highlights that a system controlled on dew point will remain in a constant mode of operation and therefore energy use compared to a system controlled by relative humidity detection should be lower.

With the tabulated air characteristics plotted on a psychrometric chart it can be seen that with dew point temperature control, under the example conditions, the supply air condition only needs to be sensibly heated or cooled and delivered to the space to allow the air changes to bring the space conditions back to set point.

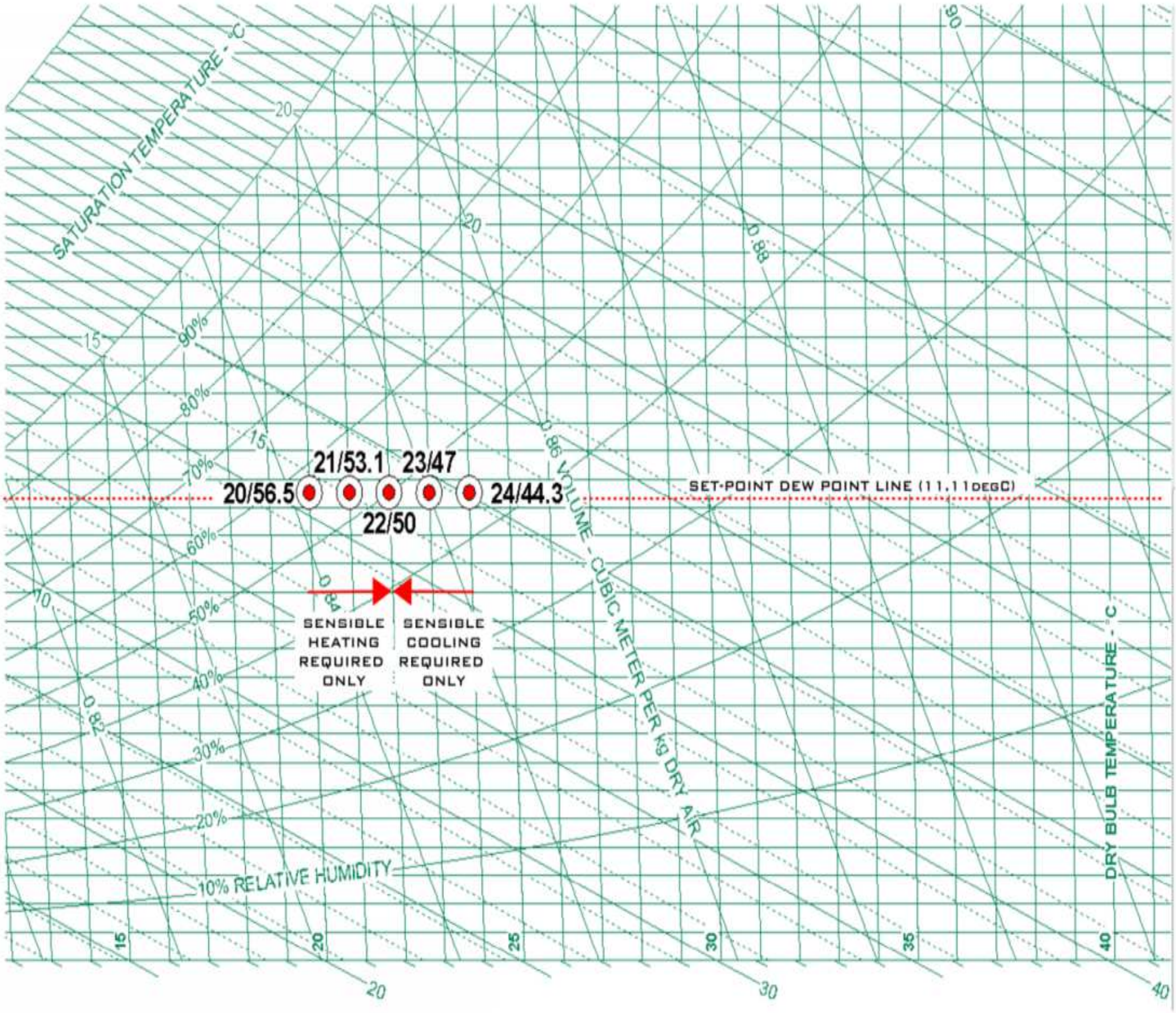

Figure 2: Psychrometric chart plot showing a constant dew point temperature with varying relative humidity points

In summary, by using dew point as the control variable, more stable conditions, system operation and energy savings may be achieved.

3.2.11 Economy Cycle

Air handling units can be specified to incorporate an economy cycle (where large amounts of outside air are used for example to provide cooling) for energy savings when ambient conditions are favourable in museum or gallery spaces which do not require close control. The control of the economy cycle mode can be based on the ambient temperature only, and the system will adjust for any changes in relative humidity set point when detected within each zone. However this approach is only recommended for artifacts which can cope with the rate of change of relative humidity. Closely controlled spaces will need to achieve more stable conditions and therefore economy cycles may not be appropriate.

3.2.12 After Hours Set Back

After hours setback of dry bulb temperatures and outdoor air quantities should be explored to provide an opportunity for greater energy savings during unoccupied hours. Rate of change considerations should always be taken into account if set backs are considered in areas housing the collection.

3.2.13 Sensor Location/Calibration

Ensure good quality sensors are employed that are suitably accurate. Ensure they are recalibrated on a regular basis rather than set and forget (at least every six months and ideally more regularly). Locate sensors in the areas that collections will be displayed – not tucked away in corners or on external walls or in the direct path of sunlight or supply air outlets.

3.3 Lighting Design Considerations

Lighting design is of key importance for the visual quality of exhibition displays and is a fundamental element in shaping the visitor's experience of an exhibition. It also is important for preventive conservation, to minimise light induced damage to collections. The following are the key considerations for lighting design in museums and galleries.

3.3.1 Spectral Characteristics

Light can be described as the visible portion of electromagnetic spectrum. In a museum context "white" light is often composed of a range of wavelengths which determine its unique qualities. The following are some key characteristics that are helpful in describing these.

3.3.1.1 Correlated Colour Temperature

Correlated colour temperature (CCT) of a light source is a measure of the hue of the white light output of that source. It is denoted in Kelvin (K) degrees that refer to the temperature of a theoretical black body radiator which, when heated up to a certain temperature, emits the same hue equivalent as the light source in question.

Practically, CCT gives an indication of how cool or how warm the light output of a light source appears. Colour temperatures of less than 3500 K are commonly referred to as "warm white". The range between 3500 K – 4500 K is "neutral white" and above 4500 K is "cool white". It must be noted that the question of how warm or how cool a light composition appears is a relative issue and the above guide on the common naming convention of relative colour temperatures is not absolute.

As a general rule, the lower the CCT of a light source, the warmer the appearance; and the higher the colour temperature, the cooler the appearance of the light source.

Figure 3: A representation of different correlated colour temperatures from warm white to cool white. The higher the Kelvin degrees, the cooler the colour appearance. (Photo: Emrah Baki Ulas)

Incandescent tungsten light sources, which used to be the dominant source of light in museums and galleries, have warm white colour temperatures typically ranging between 2700-3200 K, unless manipulated using a filter to appear warmer or cooler.

A unique aspect of incandescent sources is that as the light source is dimmed, colour temperature shifts and tends to get warmer. This natural characteristic, whilst preferable in many lighting applications, has been regarded as disadvantageous in most museum and gallery lighting applications since reduced lighting intensity often means considerable shift in the lighting tone and quality. Dimming also reduces the energy efficiency of the light source. Some museum and gallery lighting designers have used mechanical means of dimming (such as meshing or neutral density filtering). Alternative technologies such as Light Emitting Diodes (LEDs), which have become the new standard for lighting museums and galleries, eliminate this issue by providing options that achieve dimmability without a shift in the colour temperature unless it is specifically desired.

CCT can be used as a guide for understanding and communicating the colour appearance of the light. It can be measured using advanced lightmeters, however these devices may not be available in every institution. Equipment manufacturers undertake such measurements and provide information on CCT in their product literature.

3.3.1.2 Colour Rendering Index

Colour Rendering Index (CRI) is a system that indicates how well a light source brings out (renders) the colours on a surface in comparison to other light sources. CRI of a light source is denoted as a number between 0 and 100.

CRI is useful in specifying a benchmark in colour quality if it is used within its limitations. Originally, CRI was developed to compare continuous spectrum sources whose CRI's were above 90. It must be noted that it is possible to have two sources with the same CRI, but which render colour very differently, due to the nature of the measurements of CRI based on a range of sample colours.

Technically, CRI can only be compared for sources that have the same Colour Temperatures. However, as a general rule "the higher the better"; light sources with high to excellent CRI's (90-100) are considered suitable for use in museum and gallery lighting. It must also be noted that there are methods of assessing colour rendering qualities of light sources other than the CRI.

The measurement of CRI is a complex task and is normally undertaken by equipment manufacturers in lighting laboratories and the information is provided in product literature.

3.3.1.3 Spectral Wavelength Distribution

Whilst CCT and CRI provide a useful quick reference to assess the colour appearance and richness of a light source, they can be misleading. A more thorough analysis of the colour quality of a light source is possible through the evaluation of the overall colour spectrum, since it is possible to compare the performance of the light sources in the entire visible range. This, however, is a more advanced task and may require specific expertise in lighting.

The spectral colour distribution shows the composition of all visible wavelengths within the light emitted from a source. It is also useful in assessing the relative damage potential of light sources. This is due to the fact that different wavelengths of emission have different damage potential (e.g. the fading caused on an exhibition object by a light source at lower wavelengths is different to the fading caused by a light source at the higher wavelengths).

3.3.2 Spatial Characteristics

3.3.2.1 Luminous Flux

Luminous flux of a light source is the total amount of visible light emitted from it per second. In other words, luminous flux is the rate of flow of light energy and is measured in lumens.

A lumen can be thought of as a unit of power; similar to electrical power measured in “watts”.

The information on luminous flux of a light source is often provided in product literature by manufacturers. As a general rule the higher the luminous flux the more light it produces.

3.3.2.2 Light Distribution / Light Beam Characteristics

The light distribution of a luminaire determines how the light output is utilised and distributed into the space or onto an object, and plays a key role in the visual results within a museum or gallery space. It is also a determinant for how efficiently the space is illuminated, how the items are enhanced or subdued, and how well glare is reduced or eliminated. It is not a characteristic that has direct relevance to intensity or colour but to the geometry of how light is delivered into a space.

Product literature, often available in the form of an indicative beam angle, whilst not comprehensive, is a quick guide on whether the light beam is narrow or white. For instance, this kind of quick information can be used to determine whether a particular luminaire may be suitable for accent spotlighting or wallwashing techniques.

A more sophisticated method in studying the beam angle is possible through reviewing a polar light distribution diagram if it is available. Such a diagram can be generated by the equipment manufacturers or lighting laboratories, using a photogoniometer. The review and interpretation of this kind of diagram may require specific expertise in lighting.

3.3.2.3 Room Geometry and Materials

The geometry of a room and reflective qualities of its surfaces play an important role in determining the lighting within the space.

3.3.3 Environmental Characteristics

3.3.3.1 Luminous Efficacy

Luminous efficacy is a measure of the energy efficiency of a light source in terms of converting electrical energy into radiated light. It is the ratio of luminous flux to the electrical power of a light source and is measured in lumens/Watt (lm/W).

Luminous efficacy can be calculated mathematically by dividing the light power (luminous flux) by electrical power. Typically, the higher the luminous efficacy the more efficient the light source is in converting electrical enegy into light energy.

3.3.3.2 Embodied Energy, Disposal and Recycling

To make a well-rounded and thorough assessment of the environmental aspects of different lighting options, it is important to take into consideration not only the operational energy comparison but also the embodied energy, and other factors such as the cost of disposal and recycling. Whilst any positive effort to reduce the environmental impact is worthwhile, to solve the issue holistically is a complex task with many considerations and may require an environmental design specialisation.

3.3.4 Lighting Control System

Lighting Control System is an important determinant in the visual experience within a space and can enhance sustainability through providing operational advantages. Particularly with the recent shift in the lighting industry towards LEDs, Lighting Control Systems have increasingly become an important element in the overall design strategy, an energy saving measure and overall can enhance gallery/museum lighting by allowing tailored or dynamic lighting schemes. Dimmability and switching characteristics of the control systems can influence the choice of light sources and luminaires. For an optimum outcome in lighting schemes, it is critical for any institution to ensure the control systems and lighting systems are compatible with each other.

3.3.5 Operation, Maintenance and Durability

3.3.5.1 Lamp Life

It is important to note that different lamp types have different life expectancies. Since there are numerous lamp life testing methods, when evaluating the lamp life, the testing criteria needs to be reviewed to be able to do a like for like comparison. Three key factors are highlighted here as being important in considering the lamp life:

- The environmental conditions in the testing procedure (e.g. ambient temperature);
- The survival/failure rate noted in the testing procedure (e.g. life expectancy for some lamps are tested at 50% survival, whilst some are tested at 70% survival); and
- Reduction in the light output of the lamp throughout its expected life.

3.3.5.2 Future Availability

Lighting upgrades may impose a considerable cost on a regional museum or gallery. It is therefore recommended to undertake long-term planning that includes risk mitigation measures for the future of the installation, so that the institutions can maximise the benefits of any new lighting systems. Future-proofing measures include checking the potential future availability of the lamps, luminaires and/or infrastructure elements such as the track and control systems, in combination with the anticipated usable life of the system and life expectancies of the elements such as the lamps.

3.4 Lighting Design Methodologies

3.4.1 Daylighting

The oldest of all lighting techniques, daylight, is still more challenging compared to the use of electrical lighting systems, which can be more accurately planned and controlled. The dynamic and ever-changing characteristics of daylight makes it challenging to use it in museum and gallery space, but it is those same qualities that can enhance spaces significantly and provide uplifting comfort and enjoyment. Many museums and galleries have strict guidelines on the use of daylight, however carefully designed use of daylight helps save energy and increases the special quality of the exhibition spaces.

The intention should be to maximise levels of natural daylight wherever possible so as to minimise electricity consumption. However care must also be taken to minimise daylight levels to light-sensitive collections.

3.4.2 Electric Lighting

As alternative lighting technologies rapidly develop, better products are appearing in the market and the concerns in visual quality and conservation are being addressed. Alternative ways forward are opening up new possibilities for museum and gallery lighting.

The state of the LED technologies of today warrants that there are products in the market which are able to provide superior lighting solutions for gallery/museum lighting purposes. These products continue to improve. Newer technologies such as OLEDs are also likely to develop further into more practical applications including those suitable for museums and galleries.

The information contained in this section is based on the applications of LEDs as the primary light sources for museums and galleries. LEDs have various CCT options available to suit the lighting needs in museums and galleries. Some luminaire types have tuneable CCT providing added flexibility to lighting systems.

The choice of LEDs for museums and galleries should be made considering the need for excellent colour rendering abilities that achieve adequate visible colour richness suitable for most museum and gallery lighting applications. The selection of light distribution characteristics to create lighting effects such as frame spotting, accent spotting, wallwashing etc. also needs to be done mindfully to suit lighting applications.

Similar to colour rendering characteristics, the luminous efficacy of LEDs has been improving in recent years, and these sources have become highly efficient.

The light output of an LED can be utilised more effectively thanks to its physical characteristics as a small point-source quality, which is easier to optically control compared to a diffused light source. LEDs are point sources (sources in which the light is emitted from a small luminous point rather than a large luminous surface) and typically the luminous surface is considerably more compact compared to other light sources, which is advantageous in optical control. When used with suitable luminaires and optical accessories, they can be very versatile and flexible and achieve dramatic and highly textured light effects.

On the other hand, a common issue with most LED luminaires is multiple shadowing. This is due to the use of multiple LED chips in some fixtures. Depending on the optical properties of the fixture, these separate sources may create distinct shadows which may be undesirable for certain applications.

LEDs have considerably less UV and IR radiation, therefore can be considered safer in comparison to other light sources. The colour spectra of LEDs used to contain a spike in the Blue region of the spectrum, which is close to UV and can be considered to have a higher damage potential compared to the other visible wavelengths. This problem is however not as significant with the new generation of warm white LEDs which have a reduced blue spike in their light spectrum.

LED is a type of diode, and originates from the electronics industry. The disposal and recycling requirements for LEDs are similar to those for other common electronic components. Good quality LED sources, when used for suitable applications in suitable environments, can last for a very long time, therefore disposal and recycling needs for LEDs can be minimal compared to other alternative light sources.

LEDs are highly controllable, dimmable and tuneable. However, different products come with different control system compatibility. Also, some LED control methods may cause flickering at dim light levels and may not achieve smooth dimming. Control system and LED product selection needs to be done at the same time or by considering one another if/where possible.

In recent years, as more and better LED products have been appearing in the market, quality versus price has improved significantly. Nevertheless LEDs may still be considered as a costly option for existing facilities in terms of the initial replacement cost. Operational costs however are significantly less due to long lamp life. Good quality LED products typically have a lamp life of up to 50,000 hours and produce 50% to 70% of their initial light output at the end of that period. Cost assessment should include various direct and indirect factors such as the lifetime of the installation and other factors such as the quality of the desired light etc.

Future availability of a currently available device is a key issue with any technology that undergoes a rapid improvement and development. LEDs are no exception.

Independent and expert lighting design advice from a qualified professional is highly recommended for any institution that is considering LED replacement technology for their lighting systems. This is due to the fact that the LED lighting technology is complex with various parameters, and the assessment requires specific expertise as well as a wide understanding of the museum and gallery sector. It should also be noted that due to the vast differences in the quality of the components used in the manufacturing process, supply chain and the quality assurance processes, market price and performance of the LEDs may vary significantly. LED binning, colour consistency and intensity consistency should be checked for quality assurance.

3.4.3 Lighting Typologies and Spatial Planning

In a museum or gallery lighting project, whether a new-build or refurbishment, the project design teams should determine in each case which lighting typology is appropriate for the relevant applications. Although lighting for spaces within museums and galleries is generally a non-prescriptive task and each space or collection should be treated considering their own dynamics, the recommendations below, can be used as a guideline when designing the respective lighting typologies to suit the spaces and the types of collections displayed.
This section intends to provide general recommendations on the use of lighting typologies.

3.4.3.1 Lighting for Vertically Hung Displays

Wallwashing

Where illumination of the wall surfaces is required, a uniform wash of light should be provided across the vertical hanging surfaces. For an exhibition item or a field of vision to be perceived as an evenly lit surface, the proportion of maximum luminous intensity to minimum is recommended to be no more than 3:1.

To provide optimum results for the wash-lighting, the fittings or tracks should be positioned at an angle of 25°-35° from the centre of the item (average eyelevel at 1600mm).

Accent spotting

Whether independently or as an added enhancement to a base wall wash-lighting layer, supplementary spotlights can be used to add accents, highlighting individual pieces and additionally minimising shadows. These spotlights can also be used to enhance the visibility of the exhibits by keeping the overall ambient lighting levels very low and enhancing the perceived luminance of the items themselves when conservation requires low light levels.

Where accent lighting is used without the wall wash or other general ambient lighting in the background, it creates a more dramatic display and makes certain exhibits stand out.

A ratio of not larger than 5:1 for item luminance to background luminance is recommended.

To provide optimum results for accent spot lighting, the fittings or tracks should be positioned at an angle of 35°-45° from the centre of the item (average eyelevel at 1600mm).

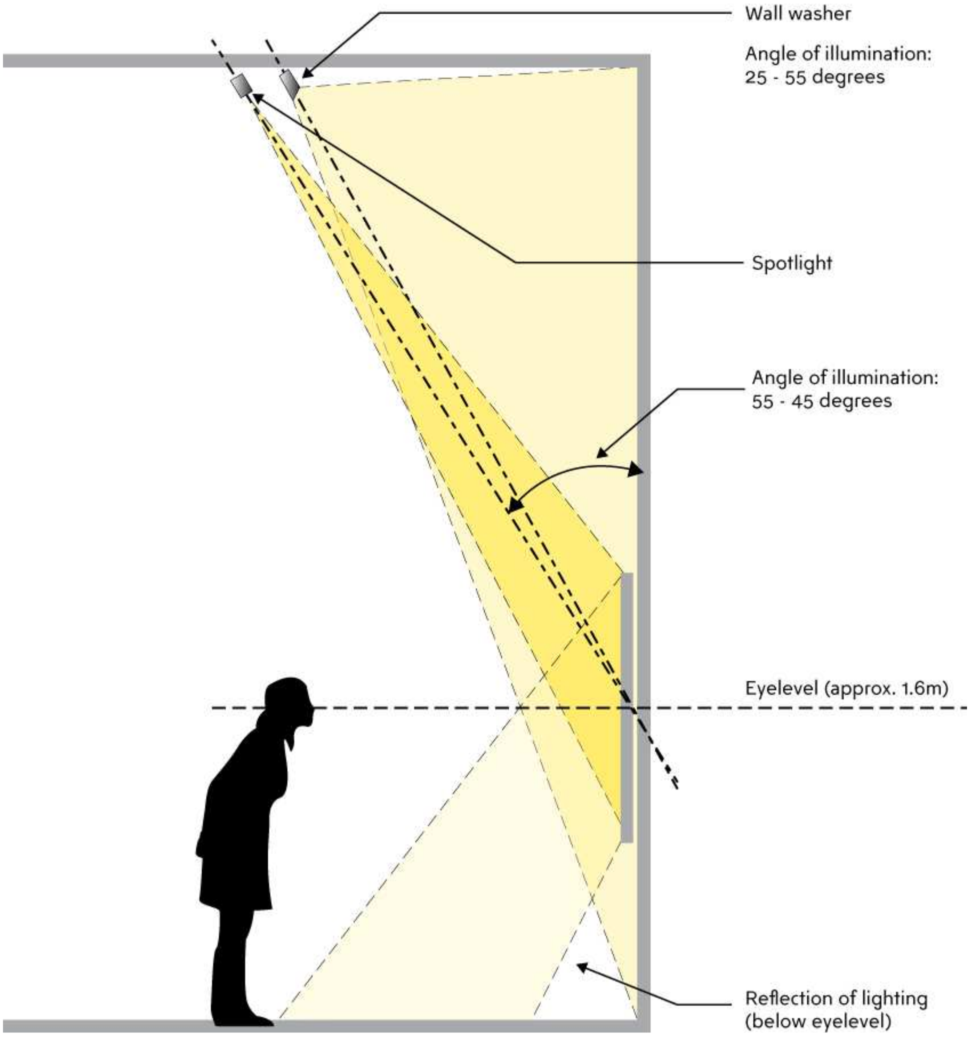

Figure 4: Lighting typologies for vertically hung displays

Frame spotting

Similar to accent spot lighting, individual pieces can be highlighted by framing spots, generally supplementary to the wash lighting. Where a more visually dramatic effect is required, frame spotting can raise the luminance of the exhibition item, precisely highlighting individual pieces. Frame spotting can minimise shadows created by the picture frames and also enhance the visibility of the exhibits when conservation requires low light levels.

A ratio of not larger than 10:1 for exhibition item luminance to background luminance is recommended.

To provide optimum results for the frame spotting, the fittings or tracks should be positioned at an angle of 35°-45° from the centre of the item (average eyelevel at 1600mm).

The lighting equipment for frame spotting often incorporates focussing lenses as well as shutter/gobo holder attachment. This type of equipment tends to be larger compared to other types of spotlights due to the optical properties and the internal accessories within the luminaire.

The lighting scheme should either comprise recessed luminaires or surface/track mounted luminaires similar to accent spotting technique.

3.4.3.2 Lighting for Free Standing Displays

Unless there is a specific curatorial reason to do otherwise, a sculpture should be lit in a way that enhances its three-dimensional shape, texture, colour and material while avoiding harsh shadows at the same time. Illuminating an item with a minimum of two spotlights shining from different directions arranged with respect to the key viewing angle creates a balanced, three-dimensional modelling effect.

To achieve the desired effect, narrow beam spotlights should be used for accentuation and minimise the light spill into the surrounds. These may be equipped with sculpture lenses elongating the beam in one direction and softening the brightness contrasts.

Displays can be illuminated with an angle of incidence of 30°-45° to the vertical. Often, the steeper the incident light, the stronger the shadows. When keeping this range of angles, strong reflection or undesirable shadows on surrounding surfaces, people and items are minimised.

Depending on the type of exhibition items, infill upward lighting may also be applied.

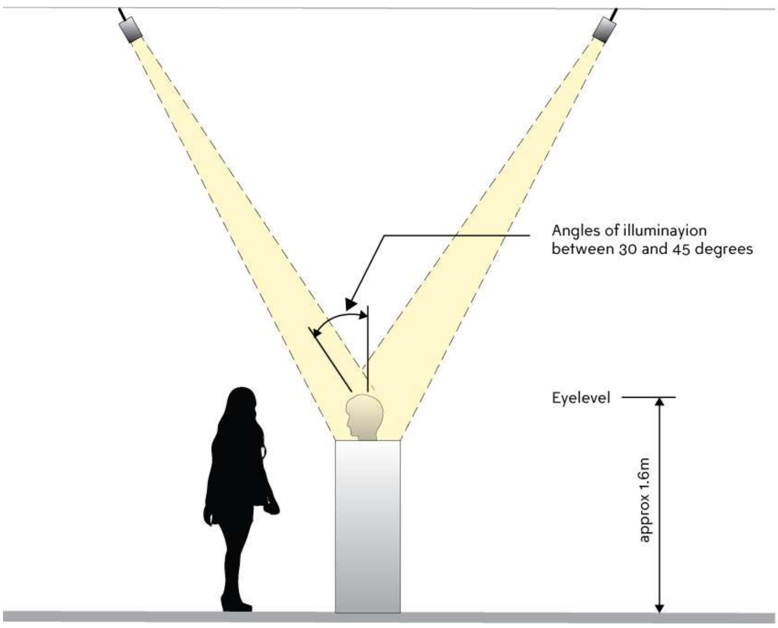

Figure 5: Lighting typologies for free standing displays

3.4.3.3 Lighting for Items in Free Standing or Integrated Joinery Type Display Cases

The strategy for the lighting of items within free standing or joinery integrated display cases is similar to lighting of free standing items on plinths.

There are, however, a range of additional considerations:

- The enclosure of the case, particularly the edge lines, where the clear glass or acrylic sides meet, may cast shadows onto the item. Depending on the size and the orientation of the item, the lighting angle may need to be adjusted to suit.

- Though often highly transparent, the surfaces of the enclosure may also be highly glossy and cause veiling reflections from a range of viewing points. Key view angles should be studied in order to ascertain the best location for light fixtures to avoid glare resulting from veiling reflections.
- In addition to glare, reflected light can impact on the overall space. Particularly in spaces with low ambient light levels, care must be taken to avoid the reflected light interfering with the lighting on other items within the space.
- Wherever it might come from, there should not be any heat induced in the closed environment of the case by any aspect of the lighting strategy or fittings.
- Display cases also present an opportunity for inbuilt lighting systems. These are often fibre optic based systems that provide localised lighting. If these systems are used it must be ensured that:
    - the light sources and the parts are adequately concealed within the enclosures at locations where they can be accessed for checking and maintenance; and
    - acoustic issues must be assessed, and the sources are aimed at angles that minimise glare.

3.4.3.4 Video/Image Media on Screen/Self-luminous Works

Exhibition spaces may contain works that have inbuilt lighting as part of the work, or works that are videos or images that are presented on screens.

Unless there is a specific requirement for supplementary external lighting for these items, the space where these items are exhibited must be darkened. If required for the circulation of the visitors and staff, supplementary low level lighting can be applied; however this lighting element should support the overall exhibition environment rather than being detrimental to it. Any spill lighting should be avoided on the display surface of these types of works. The illuminance of this orientation lighting should not exceed 10 lux on the floor. The luminance of visible marker lights if there are any should not exceed a luminance of 20 candelas/square meter.

3.4.3.5 Ambient Lighting for Buildings and Architectural Lighting

The lit appearance of the gallery or museum should primarily aim to support the visibility of the items. The lighting for architecture, however, is also important in shaping the visitor's overall experience. Architectural lighting should be an essential part of the lighting design concept. It serves the orientation of visitors and staff and the sensory perception of the architectural space, and contributes to the overall visual experience of the exhibition items.

The architectural environment shapes the experience of the museum/ gallery visit and gives the space its uniqueness. Lighting should subtly enhance architectural features or building surfaces, making the space visually appealing through variety in the lighting design. However, care has to be taken not to compete with the display or distract the visitors from the exhibits. To keep the primary focus on the display, the luminance of the space should be equal to or less than the luminance of the display walls. A 10:1 ratio of exhibit luminance to the luminance of the surrounding should not be exceeded.

The light levels have to be adjusted corresponding to the relevant conservation requirements. To not exceed the light limits for the exhibits, spill light on the exhibits has to be minimised as far as possible and a considerable degree of control (dimming, individual switching) is required.

A main principle for the architectural lighting layout is the integration of light in the architectural form. Light should be introduced into the interior without obviously employing luminaires that might detract from the overall impression of the space. All fittings used should blend in and be harmoniously incorporated into the space.

Several forms of ambient lighting can be used in order to illuminate the exhibition items. An example of this technique is the application of diffused ceiling lighting. This typology provides minimum shadows and maximum uniformity in the lighting levels.

Lighting strategies should be implemented with graduating transition spaces between high and low light level spaces. The soft graduation of light levels allows time for viewers' eyesight to adjust to display conditions contrasted to brighter areas or higher light level areas. This aspect of viewer comfort, supporting light-adaptation and dark-adaptation, should be a key consideration in future lighting strategies.

3.4.3.6 Lighting for Front of House Areas

Lighting for the entrance, the foyer and other front of house areas is paramount in forming the visitor's first impression of a museum or a gallery. The lighting in these areas not only contributes to visual comfort and supports the architectural language, but is also an important step in preparing the visitor to the exhibition spaces, by providing the required light/dark adaptation time to adjust the visual system when proceeding from very high daylight levels down to much lower exhibition lighting levels.

The range of considerations for these spaces includes the following:

- Architectural integration and seamlessness of a permanent lighting infrastructure that illuminates the building effectively;
- Lighting of exhibition items that may be located in these spaces on a temporary or semi-permanent basis (following techniques that are similar to accent spotting or frame spotting to suit);
- Event lighting integration or lighting installations that follow the themes of temporary exhibitions;
- Lighting for retail areas such as the gallery shop or the café, balanced with the rest of the front of house lighting. Use of lighting to assist orientation and navigation within the building spaces.

3.4.3.7 Lighting for Back of House Areas

The success of the institution is heavily dependent on the activities that take place 'behind the scenes', in the back of house areas. The back of house areas in a museum or a gallery may consist of various types of spaces with diverse requirements.

As an overall approach, lighting in back of house spaces should assist the users by adequately providing utmost comfort and performance for the tasks to be undertaken. The range of considerations includes:

- Lighting quality, to suit the specific needs and technical requirements (e.g. conservation, photography, design workshops etc.);
- Lighting performance, fulfilling specific visual task requirements;
- Energy performance of the lighting;
- Durability and longevity of the equipment and installation.

3.4.4 Lighting Control System Typologies

For tomorrow's gallery/museum lighting, control systems and their operation are of utmost importance. A good lighting control system will not only provide seamless operation, enhance the visual and spatial aesthetics, but will also help achieve substantial reductions in energy use, maintenance requirements and future programming. It is crucial that considerations regarding lighting infrastructure include attention to lighting controls. Often, how a lighting system is controlled can be as much or more effective in saving energy compared to what the light sources are. An important aspect is to ensure that selected light sources and the lighting control system are fully compatible. This needs to be paid attention to, in particular for LED sources.

The following are some of the methodologies that could be employed to control lighting systems more effectively in order to provide better lit environments and further energy savings:

- Ensuring full compatibility between the lighting system and lighting control system;
- Effective zoning of the lighting within exhibition spaces to suit the specific exhibition;
- Dimming of the lighting to suit each exhibition item;
- Use of timer clocks to control the lighting to suit the operational requirements;
- Use of daylight controls to dim or turn off lighting when there is sufficient daylight;
- Use of occupancy/movement sensors to dim or turn off lighting when the space is not occupied;
- Use of mobile wireless controls and programming modules that are easy to operate. These can be simple devices, used to provide the visitors with personal control over the lighting of certain items. Also, for the staff, more sophisticated programming tools can help ease the rearrangement of lighting to suit changing exhibitions and respond to top faults in a timely manner.

3.4.4.1 Traditional Hard-wired Control System

A traditional hard-wired control system consists of manual switches which activate and deactivate the luminaires through 240V copper wiring. They can have time clocks and sensors integrated into the system to automate some functions. Although generally cheaper to install, they have limitations in flexibility as future changes in layouts will require rewiring to suit.

3.4.4.2 Bus Wired Control Systems

An intelligent lighting control system is an addressable lighting management solution, providing flexibility through independent control of any circuit operated by the system. The system enables the lighting operation to be centrally programmed and adapted. These systems are generally more expensive to install but add value by minimising hard rewiring should layouts change in the future.

3.4.4.3 Control Protocols (Dimming)

Control protocols enable functionality of luminaire parameters such as intensity, colour and movement. The predominant parameter is dimmability. Dimming allows lighting levels to be adjusted to suit varying display settings and light level requirements. There are several options for dimming protocols which can be employed and each has its own advantages and disadvantages. The range of dimming protocols is outlined below:

3.4.4.4 Leading Edge

Leading edge dimmers (also known as forward phase control dimmers) work by turning off part of the leading edge of the AC sine wave for a pre-set amount of time. This results in reduced lamp output, in systems where there is a transformer, ballast, or driver device.

3.4.4.5 Trailing Edge

Trailing edge dimming is compatible with mains voltage, incandescent fittings and low voltage electronic transformers. They can be used for track lighting applications.

3.4.4.6 0-10 V

0-10 V is an electronic lighting control system where the control signal is a DC voltage that varies between zero and ten volts. The controlled lighting scales its output so that at 10 V the controlled light should be at 100% of its potential output, and at 0 V it should at 0% output (i.e. “Off”).

3.4.4.7 DALI

Digital Addressable Lighting Interface (DALI) is a protocol developed for connecting a network of luminaires and controls. This protocol creates a bi-directional flow of communication between lighting controls, luminaires and management software.

User input (e.g. switches, dimmers, pre-set scenes, LCD or CPU interface) or automatic control (e.g. passive infrared (PIR) or ultrasonic motion sensors, time clocks, photo electric cells) can communicate between each other, up to 64 devices within a DALI universe. Within this universe, luminaires controls, etc., can be grouped together and then changed with ease. Multiple DALI universes can be linked in order to control numerous devices within one network.

Each device is assigned an address which connects back to a DALI gateway or processor, allowing the user to add, delete, or regroup devices without rewiring the system. This can be beneficial for a museum or gallery, office space, or multi-purpose space that changes frequently, and can be controlled in different groups or various light level requirements.

DALI is a common protocol, based upon a technical standard IEC 62386, which enables ballasts, transformers, relay modules, emergency fittings and controllers from different manufacturers to be ‘mixed and matched’ into a single control system.

Each device is controlled through a pair of cables (twisted pair), eliminating the need for mains switching. The system transfers data bi-directionally at a consistent rate of 1,200 bits/second. Data is also sent from the luminaires to the DALI gateway and/or monitoring software, providing information on the status of the luminaire, operation of all components (lamp, ballast, dimming level, etc.), alerting maintenance staff when malfunctions have occurred.

DALI only communicates between lighting systems; but through a separate interface can connect into a BMCS (Building Management and Control System), allowing a holistic control system of various services from single point.

For substantial savings in energy use, the perspective should be widened from light sources only to include considerations for the lighting controls. Often how a lighting system is controlled can be as much or more effective in saving energy compared to what the light sources are.

The following are some of the methodologies that could be employed to control lighting systems more effectively to provide better lit environments and provide further energy savings:

- Effective zoning of the lighting within exhibition spaces to suit the using arrangements;
- Use of timer controls to control the lighting to suit the operational requirements;
- Dimming of lighting to suit the using arrangements;

- Use of daylight controls to keep the lighting off when there is sufficient daylight available;
- Use of occupancy/movement sensors to keep the lighting off when not needed.

3.4.4.8 DMX/RDM

DMX512 (Digital Multiplex) is a standard for digital communication networks that are commonly used to control stage lighting and effects. It was originally intended as a standardised method for controlling light dimmers, which, prior to DMX512, had employed various incompatible proprietary protocols. It soon became the primary method for linking controllers (such as a lighting console) to dimmers and special effects devices such as fog machines and intelligent lights. DMX has also expanded to uses in non-theatrical interior and architectural lighting, at scales ranging from strings of Christmas lights to electronic billboards. DMX can now be used to control almost anything, reflecting its popularity in theatres and venues.

Remote Device Management or RDM is a protocol enhancement to DMX512 that allows bi-directional communication between a lighting or system controller and attached RDM compliant devices over a standard DMX line. This protocol allows configuration, status monitoring, and management in such a way that does not disturb the normal operation of standard DMX512 devices that do not recognise the RDM protocol. Currently, there are limited products available which are RDM compatible.

With thoughtful planning and consideration of the uses of each space, the lighting can be divided into groups or zones of lights, in which all lights in a group are switched together, but independently of other groups. This strategy can be applied to either intelligent control systems or traditional hard-wired control systems.

3.4.5 Input Devices and Control Interfaces

3.4.5.1 Time Clocks

In spaces where patterns of occupancy are predictable, the use of time clocks to automate switching on and off of lighting is a cost effective strategy. Time clocks can be used in conjunction with manual switching. When time clocks are used in traditional hard-wired systems, it is common for them to control a number of lighting circuits or switching groups. In this capacity, time clocks are relatively cheap.

3.4.6 Sensors

3.4.6.1 Occupancy Sensors

Motion sensors are an affordable control device which can be employed in both new and existing installations to reduce energy consumption. Lighting can be programmed to automatically switch off or dim when no motion is detected after a predetermined time. Further, motion sensors can be used to activate lighting when motion is detected within range of the sensor. This is most applicable for galleries/museums which have a number of separate spaces.

3.4.7 Light Sensors

Photo Electric (PE) Cells detect the quantity of visible light falling on them and trigger an action in the lighting or shading system. They can be used in spaces which have a daylight component significant enough to allow a safe and comfortable environment, without the need for supplementary electric lighting.

When an adequate level of daylight is detected, electric lighting can be switched off or dimmed. PE cells can also be used in spaces containing sensitive collections to switch off or dim lighting or close blinds/shading devices, once a certain threshold is reached.

The key to achieving the most out of any sensors is to ensure they are accurately calibrated. A poorly calibrated system may result in a poor occupant and visitor satisfaction level and increased energy consumption. Sensors should be calibrated by qualified persons during commissioning and recalibrated at 3 year intervals to ensure optimised operation of this control strategy.

4.0 Sustainable Design Strategies

This section focuses on sustainable outcomes, and within this context details the relative merits and cost of a wide range of solutions that can be considered when seeking to resolve or improve climate control and lighting issues.

The museum and gallery sector, like most other industries, faces challenges and problems in reducing energy consumption and therefore its carbon footprint and, of course, running costs. There are examples of initiatives in other industries that the museum and gallery sector can learn from, but in order to really make headway in terms of changing prescribed parameters, it is necessary to rethink long-established policies and approaches to collection preservation relative to environmental conditions.

Internationally, several museum, gallery and library institutions have been leading the way in rethinking the conditions in which we are required to preserve items of cultural significance. The desire is driven as much by social responsibilities in protecting our natural environment as a need to reduce costs and control expenditure.

Previous sections of this Guide have discussed in detail a range of considerations that can be reviewed in order to provide an opportunity to reduce energy consumption in museums. These and other initiatives are discussed here to act as prompts, aiding institutions in moving towards their sustainability goals.

4.1 Energy Hierarchy

One of the greatest challenges for today's museums and galleries is to reduce their energy consumption, while maintaining their specific functional needs. Typically, these buildings consume energy, principally in the process of environmental control in mediating between the external climate and the internal environment. Lighting and equipment also consume a significant proportion of energy.

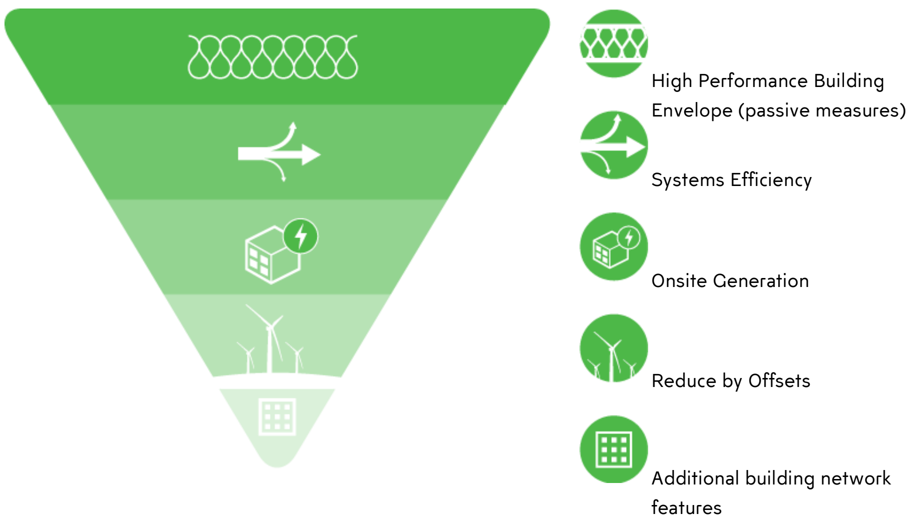

Figure 6: Energy Hierarchy for buildings

The "energy hierarchy" defines an integrated approach to the management of energy demand and supply. The energy hierarchy has the reduction of energy use as its first priority, and then seeks to meet the remaining energy demand by the most efficient means applicable, before the inclusion of on-site generation and importation of green power.

A possible optimum approach to reducing a museum or gallery's energy usage is outlined below:

- Minimise energy consumption – through high efficiency building envelope (passive initiatives);
- Efficient energy use – through high efficiency systems and smart operation;
- Maximise on-site renewable energy production – solar hot water, thermal, photovoltaics, wind;
- Encourage operational training and education – by providing building user guides.

The following sources of energy should be utilised, in the following order of priority:

- Renewable sources – such as on-site renewable electricity generation and solar hot water systems and use of green power;
- Natural gas;
- Grid electricity.

4.2 Initiatives

There are many ways museums and galleries can work towards becoming more energy efficent and sustainable. Key initiatives include reviewing climate control specifications and using energy efficient lighting as discussed in the previous sections of this Guide.

These initiatives and others associated specifically with the building and its environmental systems are outlined on the following pages in a simple matrix format intended to prompt and inform sustainable decision making.

A well-considered policy and plan that includes a method of tracking the progress and success (or otherwise) of sustainable initiatives is critical for achieving sustainability and should be developed.

The initiatives chart is developed for existing museums and galleries. For new facilities, whilst the chart will be useful, initiatives should be developed in line with the energy hierachy described previously where passive measures would form part of a primary focus before moving onto active systems.

It may often be difficult to apply these passive measures to existing buildings (eg. added shading, increased thermal mass/increased hygroscopic buffers/improved air tightness etc.), but any opportunity to improve passive control should be explored.

It is important to note other sustainability criteria (social/economic/supply chain/transport/water etc.) should also form part of the wider sustainability strategy for a gallery/museum, though do not form part of this initiatives chart. Where practicable, such initiatives should be considered in addition to the following matrix:

Key to Initiatives Chart

Category	Notes	Level	Description
Invasiveness	Provides an indication of the likely extent to which the proposed strategy will impact on an existing gallery or museum in terms of its operations and/or impact on existing buildings and services while work is underway to implement this initiative	Minimal	Non-invasive work
		Low	Minor disruption
		Med	Significant impact
		High	Major – complete refurbishment likely
Cost	Provides an indication of the likely broad order of cost associated with undertaking the initiative	Minimal	Negligible cost
		Low	Low cost
		Med	Considerable cost
		High	Substantial cost likely to require special funding stream
Sustainability Benefit	Provides an indication of the likely sustainability benefit of the initiative once successfully implemented	Minimal	Negligible Benefit
		Low	Minor Benefit
		Med	Considerable Benefit
		High	Substantial Benefit

Table 2: Key to initiatives chart

CLIMATE CONTROL	Category	Level: Low / Medium / High
Review environmental standards and modify set points Relaxing environmental set points can save considerable energy particularly in conjunction with a seasonal adjustment control strategy (NB: ensure rates of change limits are maintained during seasonal set point change over periods).	Invasiveness Cost Sustainable Benefit	
Organise exhibitions to suit level of conditions required Tailor exhibitions where possible so that those requiring higher levels of environmental protection are together and/or consider display cases/local conditioning, therefore providing the potential to limit the number of highly conditioned large exhibition/storage volumes.	Invasiveness Cost Sustainable Benefit	
Zoning Zone systems so that only areas requiring higher levels of environmental control are receiving it.	Invasiveness Cost Sustainable Benefit	
Position of collection items Locate items requiring tighter environmental controls in areas that have good passive control and away from sources of solar gain etc.	Invasiveness Cost Sustainable Benefit	
Ensure controls are working properly Incorrectly commissioned or functioning controls can significantly impact on energy consumption as well as impact on stability of conditions in critical spaces as well as human thermal comfort.	Invasiveness Cost Sustainable Benefit	
Heat rejection plant set points Review heat rejection plant set points to ensure optimum operation with respect to local climatic conditions – it may be possible to shift these set points across the seasons to better match equipment efficiencies.	Invasiveness Cost Sustainable Benefit	
Modify flow and return temperatures Investigate possibility of modifying typical heating and chilled water temperatures, including chilled water reset strategies, to better match installed equipment optimum operational conditions (whilst always remembering the need to control humidity).	Invasiveness Cost Sustainable Benefit	
Rebalance and re-commission all plant Vent and a/c plant does not stay commissioned and balanced indefinitely (indeed it may never have been appropriately balanced and commissioned initially). Rebalancing and re-commissioning ensures plant and equipment operates as efficiently as possible.	Invasiveness Cost Sustainable Benefit	
Check and repair duct leakage Duct leakage increases energy usage and reduces system ability to maintain required conditions.	Invasiveness Cost Sustainable Benefit	
Heat recovery ventilation Heat recovery systems transfer useful energy from	Invasiveness	

outgoing (exhaust) air to incoming (outside) air, therefore reducing the amount of energy required to condition the incoming air.	Cost Sustainable Benefit
Use Low Pressure Hot Water (LPHW) for zone reheat Avoid the use of inefficient electrical reheat – replace with LPHW zone reheat wherever possible.	Invasiveness Cost Sustainable Benefit
Introduce variable speed pumps and fans Variable speed motors work by reducing electrical frequency (and therefore energy) to match decreasing loads. Care should be taken when considering variable speed fans serving critical spaces to ensure pressurisation regimes are maintained.	Invasiveness Cost Sustainable Benefit
Digital control systems Digital control systems enable control of flow rates and set points of most plant and equipment and therefore accurate and efficient operation.	Invasiveness Cost Sustainable Benefit
Check ductwork and pipework insulation Well insulated pipes and ducts reduce energy losses and improve control.	Invasiveness Cost Sustainable Benefit
Replace Heating, Ventilation and Air Conditioning systems New, more efficient HVAC systems (either constituent system parts or comprehensive replacement) employing modern, efficient technologies.	Invasiveness Cost Sustainable Benefit
Passive environmental control see note 1 Reliance on active HVAC systems can be reduced and in some cases removed through the application of passive strategies (natural ventilation/mixed mode systems/economy cycles/night purge/exposed thermal mass/hygroscopic buffers/performance glazing/shading devices).	Invasiveness (see note 2) Cost (see note 2) Sustainable Benefit

Table 3: Energy – Climate Control initiatives

Notes:

1) Passive strategies generally will need to be considered in conjunction with relaxed environmental set points and may be difficult to achieve in existing buildings but providegreat potential for energy savings.
2) The term 'Passive Initiatives' can refer to a number of different things – from adding external shading (which may not cause a huge disturbance to operation, but can be costly) to incorporating natural ventilation strategies (which may result in more disturbance while work is underway as well as being costly). All well planned and executed passive strategies should however deliver significant sustainability benefits.

LIGHTING	Category	Level (Low / Medium / High)
Programmable lighting controls Lighting control systems can switch off lights automatically or reduce levels to suit particular scenarios, therefore reducing energy.	Invasiveness Cost Sustainable Benefit	
Daylighting control Where spaces incorporate both daylight and artificial light, controls should be in place that hold off artificial sources unless they are required to operate.	Invasiveness Cost Sustainable Benefit	
Controls and dimming Provide individual control of each lamp on a track so each can be individually dimmed. Consider addressable lighting.	Invasiveness Cost Sustainable Benefit	
Switching strategy Simple and understandable switching arrangement will help users recognise what controls what and therefore encourage appropriate operation. Individual spaces should be individually switched.	Invasiveness Cost Sustainable Benefit	
Display case lighting Lighting strategy for display cases must be specifically tailored in order to both ensure efficiency and meet conservation obligations.	Invasiveness Cost Sustainable Benefit	
Lighting optimisation Review existing lighting. Identify where lighting levels can be reduced or changed to improve efficiency. Confirm light sources are efficiently aimed and there is no light spill.	Invasiveness Cost Sustainable Benefit	
LED lighting LED lighting can offer significant energy savings and lamp longevity in comparison to traditional sources. Care is required to avoid issues with colour rendering and temperature. Retrofitting often possible.	Invasiveness Cost Sustainable Benefit	
Out of hours strategy Different requirements will be required during normal operational hours and out of hours. Having dedicated lighting strategies to suit can conserve energy.	Invasiveness Cost Sustainable Benefit	
Zoning in non-public spaces For areas such as large storage spaces where only particular and limited areas will be in use at any given time, appropriate controls and circuiting will ensure only the relevant areas are lit. Similarly office spaces should be zoned to max $100m^2$ to ensure areas that do not need to be lit or that require lower lighting levels are not lit unnecessarily.	Invasiveness Cost Sustainable Benefit	
Occupancy sensors		

Stand alone or centrally controlled occupancy sensors will ensure intermittently occupied spaces are only lit when in use.	Invasiveness Cost Sustainable Benefit	

Table 4: Energy- Lighting initiatives

ELECTRICAL	Category	Level: Low	Medium	High
Green energy procurement Procurement of energy from a supplier that is sourced from an accredited renewable generation source will significantly reduce museum/gallery carbon footprint.	Invasiveness Cost Sustainable Benefit			
On site renewable energy generation Renewable energy sources such as photovoltaic panels are becoming more affordable and therefore payback periods are reducing.	Invasiveness Cost Sustainable Benefit			
Time switches Automatically switches off equipment to avoid unnecessary energy usage when not required.	Invasiveness Cost Sustainable Benefit			
High efficiency motors Upgrading to high efficiency motors wherever possible will reduce energy and increase reliability.	Invasiveness Cost Sustainable Benefit			
Power factor correction Units are becoming more cost effective all the time and increasing power factor as close as possible to unity increases energy efficiency.	Invasiveness Cost Sustainable Benefit			
Last man out switch All non-essential equipment and lighting can be powered down by a single off switch, thereby reducing unnecessary energy use.	Invasiveness Cost Sustainable Benefit			

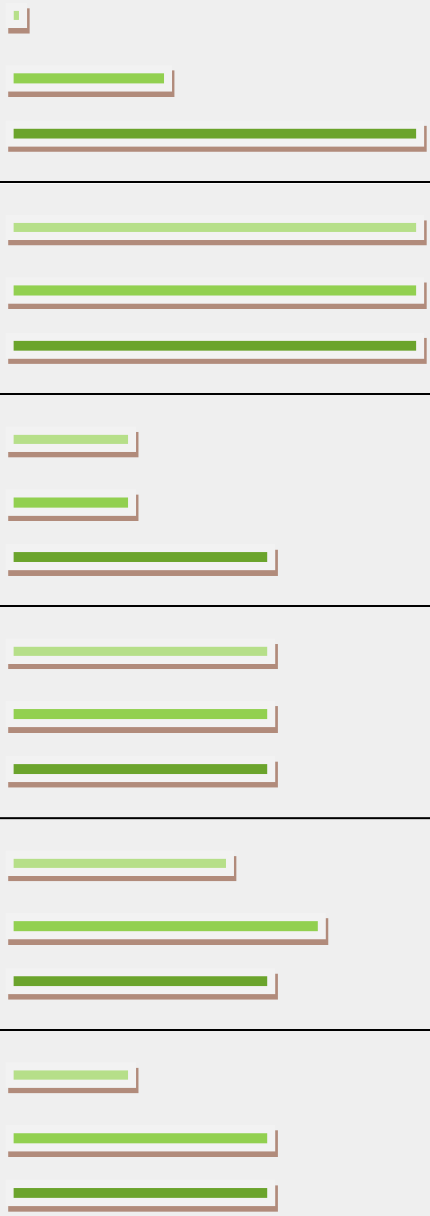

Table 5: Energy – Electrical initiatives

MANAGEMENT	Category	Level Low / Medium / High
Responsive and proactive facilities management (FM) Engage an FM team (either in house or external) that undertakes preventative maintenance (rather than reactive) and that responds quickly and effectively to issues will help to ensure that equipment operates efficiently and that issues that are reported are not ignored.	Invasiveness	
	Cost	
	Sustainable Benefit	
Sub metering Sub meter significant energy and water uses to allow more detailed analysis and inform decisions on system modifications and upgrades.	Invasiveness	
	Cost	
	Sustainable Benefit	
Energy targets and monitoring Set targets to allow the building to be objectively measured. Compare against industry benchmarks (IAMFA or similar) – normalised to suit climatic conditions etc.	Invasiveness	
	Cost	
	Sustainable Benefit	
Staff Feedback/Staff buy in Initiate formal staff feedback – can identify any areas of museum/gallery underperformance as well as operational issues. Raise awareness of staff of sustainability issues (sustainability guide?) to encourage 'buy in' by all in moving towards sustainable goals.	Invasiveness	
	Cost	
	Sustainable Benefit	
Building Management System (BMS) trend logging (NB – assumes a BMS is already in place) Monitor and review BMS trends and equipment operational characteristics to ensure not only that appropriate conditions are being delivered but that they are being delivered efficiently (for example is an averaging or high select control most appropriate?).	Invasiveness	n/a
	Cost	
	Sustainable Benefit	
Temperature and Relative Humidity sensor locations Ensure sensors are installed in locations that are representative of the location of the collection the systems are trying to protect.	Invasiveness	
	Cost	
	Sustainable Benefit	
Temperature and RH sensor calibration Regularly calibrate sensors to ensure accurate control system feedback.	Invasiveness	
	Cost	
	Sustainable Benefit	
User guide/user training Develop a user guide and undertake training on energy, waste and water issues associated with the gallery/museum to facilitate management.	Invasiveness	
	Cost	
	Sustainable Benefit	
Up to date and comprehensive operation and maintenance manuals Accurate details of what equipment is installed on a site, where it is, how old it is and how it needs to be operated and maintained will aid in ensuring the equipment operates effectively. It may also confirm that the equipment is appropriate or not fit for purpose.	Invasiveness	
	Cost	
	Sustainable Benefit	
Environmental management system Such a system can be used to track energy, water and	Invasiveness	

waste generation and provide a feedback mechanism.	Cost	
	Sustainable Benefit	

Table 6: Energy - Management initiatives

5.0 Practical Implementation Guide

This section provides a practical implementation plan for assessing a collection and building, and a process to follow in moving towards more sustainable outcomes.

5.1 Design Process, Communication and Integration

From the initial stages of design when environmental requirements are assessed and appropriate strategies are selected, strong communication between all members of the design, construction and operational teams is essential for effective ongoing implementation of the design intent.

At the beginning of the design process, the museum or gallery must be involved in defining the expectations and limitations of the project, together with, but not limited to, the mechanical and electrical engineers, architect, interior designer, facilities management, collection managers, administrators, curators, conservators and security personnel.

Input from the building operators at the design stage will ease the handover period and long-term operation of the museum/gallery facility, contributing to energy, cost and carbon savings throughout the whole project lifetime. Engaging with conservation teams early on will aid in everyone embracing the need to reduce energy whilst giving due regard to protection needs.

There are always conflicting requirements from different stakeholders – it is incumbent on the client to help align these requirements and therefore allow the design team to proceed with confidence.

The following sections of the report are intended to provide a simple design framework for the key areas explored in this report – environmental parameters, sustainable air conditioning and sustainable lighting approaches.

Once the collection is classified and initial requirements set, the flow charts are intended as a tool for use by all involved in the design, construction and operation of museum and gallery buildings to aid selection of the most appropriate and effective climate control and sustainability strategies in conjunction with the initiatives matrix.

5.2 Establishing A Design Approach

The process of achieving an optimum outcome for the care of a collection in an age of energy efficiency and sustainability is now a more complex process than when a simple single standard applied. No longer is it acceptable to climate control an entire museum to levels that cater to the most vulnerable part of the collection. As has been previously cited from PAS 198, it now requires evidence based risk-managed, holistic approach to environmental management for the collection. It should always start from the collection itself and then expand out to take account of the building envelope, the capacity of the climate control system and finally the risks that need managing.

This can be approached in a four-stage process:

1) Understanding the sensitivities and vulnerabilities of the collection, i.e. its susceptibility to damage by poor environmental conditions.
2) Establishment of the environmental requirements for the collection arising from point 1, which may be varied.

3) Understanding the capacity of the building, climate control and lighting systems to deliver the required environment.
4) Engaging in dialogue with all interested parties to agree on an optimum outcome which takes into account the above points 1, 2 and 3.

5.2.1 Understanding the Collection

Establishing the optimum environmental parameters for the care of a collection must always start from an understanding of the collection itself, its material composition and vulnerabilities. For instance, the demands of a collection of paintings on wood, which are highly vulnerable to damage from fluctuations in relative humidity, causing the paint to flake, will be different from those of a collection of ceramics, which can cope with substantial environmental extremes.

The first step is to categorise the collection according to material type. There are various sources that look at grouping material types for this purpose, including ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers) guidelines, PAS 198 (Publicly Available Specification 198) and other conservation/collection management publications, so there is no one right way, but the following is a useful starting point:

1	Digital Content (CD, tapes, hard drives)
2	Film, negatives
3	Photographs
4	Plastic, rubber, modern materials (acrylics)
5	Parchment, vellum, skin, bone, ivory
6	Dyes, pigments, paints, ink
7	Paper
8	Leather
9	Paintings
10	Textiles, basketry
11	Wood
12	Metal
13	Stone, ceramics, glass

There are benefits in categorising the collection into these material types in either a percentage of the total collection or numbers of objects. The level of detail required is not critical, the idea being to provide an overview of the collection material types. When categorising composite objects made from more than one material, categorisation should be according to the most sensitive or vulnerable material. For example, ivory buttons on an Asian textile would be categorised as ivory rather than textile.

The second step is to understand the sensitivities and vulnerabilities of these material types so as to inform the next stage. The following table summarises these:

	Light sensitivity	Sensitivity to Temp	Sensitivity to RH fluctuation	Pollutant sensitivity
Film, negatives	High	Medium	Medium	High
Photographs	High	Medium	Medium	Medium
Plastic, rubber, modern materials	Medium	Medium	Medium	Medium
Parchment, vellum, skin, ivory	Medium	High	Medium	Medium
Dyes, pigments, paints, ink	High	Low	Low	Low
Paper	Medium	Medium	Medium	Low
Leather	Medium	Medium	Medium	Low
Textiles, basketry	High	Medium	Medium	Low
Paintings	Medium	Medium	Medium	Medium
Wood	Medium	Medium	Medium	Low
Metal	Low	Low	Low	Low
Stone, ceramics, glass	Low	Low	Low	Low
Digital content (CD, tapes, hard drives)	Low	Medium	Medium	Medium

Table 7: Material environmental tolerances

This process is designed to clarify the broad requirements of each material type and to highlight those material types in the collection which need special care. The particular damages due to inappropriate relative humidity, temperature or lighting are detailed below:

	Relative humidity		Temperature		Lighting	
	Too low	Too high	Too low	Too high	Too low	Too high
Film, negatives	Flaking, delamination, brittleness, curling	Softness, stickiness, mould growth, decay of colour, Vinegar Syndrome		Increased degradation		Chemical degradation
Photographs	Drying, breaks, deformation, delamination	Condensation, deformation, stickiness, silver mirroring, mould growth		Dye fading, Vinegar Syndrome		Damaged photographic emulsions
Plastic, rubber, modern materials	Fractures, brittleness, delamination	Swelling, delamination, electrostatic charge	Deformation, brittleness,	Brittleness, cracks, deformation, fading, yellowing, browning		Chemical degradation
Parchment, vellum, skin, ivory	Stiffness	Cockling, distortion, separation of paint/ink, mould growth	Distortion	Softening		Chemical degradation
Dyes, pigments, paints, ink		(irongall ink) Corrosion		(digital ink) dye migration, (irongall ink) corrosion		Fading and chemical degradation
Paper	Brittleness	Mould growth, yellowing		Discolouration, stiffness		Fading, weakening and yellowing
Leather	Drying, breaks	Shrinkage, brittlement, mould growth		Inflexibility, hardening		Degraded leather book bindings
Textiles, basketry	Brittleness, delamination, deformation	Dye fading, mould		Dye fading, weakening		Fading, breakdown of fibres
Paintings	Oil films can crack, flaking	Cracking, delamination, distortion, mould growth				Fading
Wood	Delamination, deformation, cracks, drying	Distortion, mould growth				Fading and oxidation of surfaces
Metal		Corrosion, tarnishing				
Stone, ceramics, glass	Drying, cracking, flaking	Crizzling, weeping, cracking, crystallisation, powdering, delamination		Crystallisation, powdering, delamination		
Digital content (CD, tapes, hard drives)	Flaking, delamination, brittleness, curling	Softness, stickiness, mold growth		Increased degradation		Chemical degradation

Table 8: Material damage due to inappropriate relative humidity, temperature or light

5.2.2 Establishing the Environmental Requirements

With the collection's sensitivities and vulnerabilities understood, the next stage is to establish the broad appropriate environments for its care. This can be achieved by using the information gained to divide the collection into three strands as follows, based on an assessment of the level of risk of damage that would be caused by a poor environment. In turn this will determine the type of environment in which they should be placed:

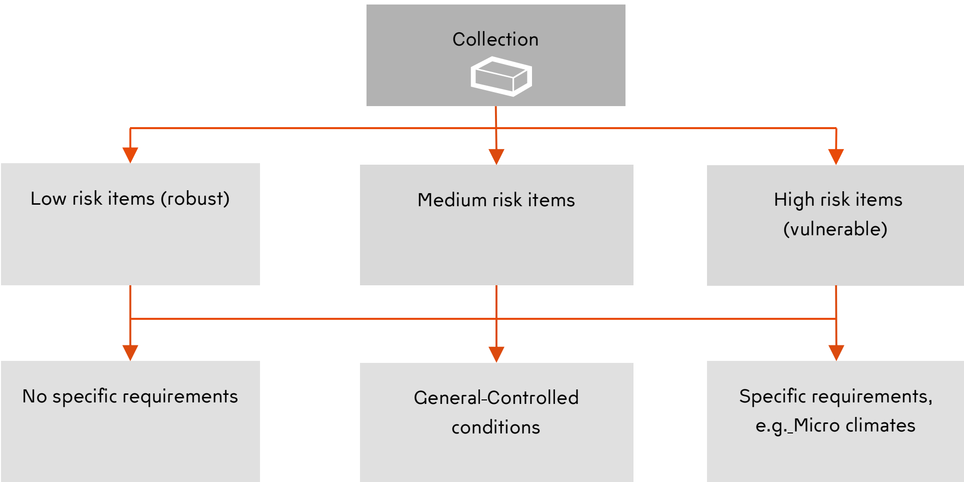

Figure 7: Environmental requirements

As can be seen, parts of the collection that may have been identified as medium risk may still be deemed as requiring highly controlled environments (e.g. a textile that is susceptible to mould growth), or conversely minimal environmental control (e.g. a highly robust piece of furniture).

5.2.3 Understanding the Building Systems

The information on the collection gained in previous stages now needs to be considered alongside an understanding of the physical capacity of the building and the plant to provide controlled environmental conditions.

This requires monitoring the environment where this has not already been undertaken. Data loggers are the standard way to gain this information, but the old style thermo-hydrographs are equally effective, albeit rather more labour intensive. Generally speaking, the longer period the data has been gathered for (at least a year), and the more areas of the building that are being monitored, the more useful the data is in providing information for understanding how the building and the plant are performing.

Data logging information will only ever tell part of the story however, and visual observations of the way in which material types are responding to the local environment where they are already exhibited or stored will assist further in understanding the building and systems performance.

Understanding the construction of the building and how the climate control and lighting systems are organised, i.e. what plant is serving what area of the building is also critical to this process.

Of particular interest should be the establishment of areas of the building where the environment is more stable. Typically these will be internal areas at ground level or below ground.

An important initiative in this respect may be to create a Building User Guide (BUG) that can summarise various aspects of building services and systems in graphic and brief representations. This enables the building occupants and users to understand the design intent and help them operate the building in a more effective way to suit their needs.

5.2.4 Reaching an Optimum Environmental Outcome

Reaching an optimum outcome on the establishment of an environment which takes into account the collection sensitivities, the performance capacity of the building and plant, what is practically achievable and affordable and any sustainability requirements is the final stage of the process. This needs to include dialogue between all relevant parties including the executive, collection managers, conservators, and building managers, as each has an interest in the outcome.

It is at this stage that the risk assessment process will need to come to the fore, as any setting of environmental levels has a risk profile ranging from minimal to major. The ASHRAE Temperature and Relative Humidity Specification for Collections is the best and most widely recognised guide to assessing these risks, providing a range of settings with the commensurate risks and benefits of each. (Table 9)

<table>
<tr><td colspan="6">Temperature and Relative Humidity Specifications for Collections</td></tr>
<tr><th rowspan="2">Type</th><th rowspan="2">Set Point or Annual Average</th><th colspan="3">Maximum Fluctuations and Cradients in Controlled Spaces</th><th rowspan="2">Collection Risks and Benefits</th></tr>
<tr><th>Class of Control</th><th>Short Fluctuations plus Space Gradients</th><th>Seasonal Adjustments in System Set Point</th></tr>
<tr><td rowspan="6">General Museums, Art Galleries, Libraries, and Archives

All reading and retrieval rooms, rooms for storing chemically stable collections, especially if mechanically medium to high vulnerability.</td><td rowspan="6">50% RH (or historic annual average for permanent collections)

Temperature set beteen 59 and 77°F (15 and 25°C)

Note: Rooms intended for loan exhibitions must handle set point specified in loan agreement, typically 50% RH, 70°F (21°C), but sometimes 55% or 60% RH.</td><td>AA
Precision control, no seasonal changes</td><td>±5% RH, ±4°F (±2°C)</td><td>Relative humidity no change
Up 9°F (5°C); down 9°F (5°C)</td><td>No risk of mechanical damage to most artifacts and paintings. Some metals and minerals may degrade if 50% RH exceeds a critical relative humidity.
Chemically unstable objects unusable within decades.</td></tr>
<tr><td rowspan="2">A
Precision control, some gradients or seasonal changes, not both</td><td>±5% RH, ±4°F (±2°C)</td><td>Up 10% RH, down 10% RH
Up 9°F (5°C); down 18°F (10°C)</td><td rowspan="2">Small risk of mechanical damage to high vulnerability artifacts; no mechanical risk to most artifacts, paintings, photographs and books.
Chemically unstable objects unusable within decades.</td></tr>
<tr><td>±10% RH, ±4°F (±2°C)</td><td>RH no change
Up 9°F (5°C); down 18°F (10°C)</td></tr>
<tr><td>B
Precision control, some gradients plus winter temperature setback</td><td>±10% RH, ±9°F (±5°C)</td><td>Up 10%, down 10% RH
Up 18°F (10°C), but not above 86°F (30°C)</td><td>Moderate risk of mechanical damage to high vulnerability artifacts; tiny risk to most paintings, most photographs, some artifacts, some books;
no risk to many artifacts and most books.
Chemically unstable objects unusable within decades, less if routinely at 86°F (30°C), but cold winter periods double life.</td></tr>
<tr><td>C
Prevent dampness (or other high-risk extremes)</td><td colspan="2">Within 25 to 75% RH year-round
Temperature rarely over 86°F (30°C) usually below 77°F (25°C)</td><td>High risk of mechanical damage to high-vulnerability artifacts; moderate risk to most paintings, most photographs, some artifacts, some books; tiny risk to many artifacts and most books.
Chemically unstable objects unusable within decades, less if routinely at 86°F (30°C), but cold winter periods double life.</td></tr>
<tr><td>D
Prevent dampness (or other high-risk extremes)</td><td colspan="2">Reliably below 75% RH</td><td>High risk of sudden or cumulative mechanical damage to most artifacts and paintings because of low-humidity fracture; but avoids high-humidity delamination and deformations, especially in veneers, paintings, paper, and photographs.
Mold growth and rapid corrosion avoided.
Chemically unstable objects unusable within decades, less if routinely at 86°F (30°C), but cold winter periods double life.</td></tr>
<tr><td rowspan="2">Archives, Library

Storing chemically unstable collections</td><td>Cold Store:
-4°F (20°C), 40% RH</td><td colspan="3">±10% RH, ±4°F (±2°C)</td><td>Chemically unstable objects usable for millennia.
Relative humidity fluctuations under one month do not affect most properly packaged records at these temperatures (time out of storage becomes lifetime determinant)</td></tr>
<tr><td>Cool Store:
50'F (10°C)
30 to 50% RH</td><td colspan="3">(Even if achieved only during winter setback, this is a net advantage to such collections, as long as damp is not incurred)</td><td>Chemically unstable objects usable for a century or more. Such books and papers tend to have low mechanical vulnerability to fluctuations.</td></tr>
<tr><td>Special Metal Collections</td><td>Dry room:
0 to 30% RH</td><td colspan="3">Relative humidity not to exceed some critical value, typically 30% RH</td><td></td></tr>
<tr><td colspan="6">Note: Short fluctuations means any fluctuation less than the seasonal adjustment. However, as noted in the section on Response Times of Artifacts, some fluctuations are too short to affect some artifacts or enclosed artifacts.</td></tr>
</table>

Table 9: (Adopted Table from) ASHRAE Temperature and Relative Humidity Specifications for Collections

No two collections are identical. Ideally, temperature and humidity targets and tolerances for each facility are developed collaboratively by a conservator with expert knowledge of the damage factors and realities of the collection, and a design engineer with extensive experience in designing systems that meet the needs of many different types of collections. That approach ensures specifications most likely to provide maximum life for the collection. Experienced experts are best equipped to identify areas of special risk and devise solutions, and to properly manage economic and other tradeoffs, although this level of expertise is not always available.

Table 9 summarises the probable effects of various specification options, based on the best current knowledge (including all available data, research results, and judgment of conservators) divided into reduced permissible fluctuations to five classes: AA, A, B, C, and D. Gradients are conservatively considered to add to short-term fluctuations because artifacts can be moved from one part of a space to another, adding a space-gradient fluctuation to the dynamic fluctuations of the HVAC.

Class AA control has the highest potential for energy consumption and affords no protection to historic buildings in cold climates. Older buildings are at most risk to damage from condensation on windows, walls, and roofs. Therefore, HVAC application in historic buildings must consider the risk to the structure and building envelope. Class A control has the benefit of some reduction of energy consumption and, with seasonal lowering of the relative humidity set point in the winter, affords some protection to historic buildings in cold climates. Older buildings at these lower temperature and relative humidity specifications are at less risk to damage from condensation on windows, walls, and roofs.

Class A is the optimum for most museums and galleries. Two possibilities with equivalent risks are given: a larger gradient and short-term fluctuations, or a larger seasonal swing. Stress relaxation is used to equate ±10% relative humidity seasonal swing to a short ±5% relative humidity. A major institution with the mandate and resources to prevent even tiny risks might move toward the narrower fluctuations of Class AA. However, design for very-long-term reliability must take precedence over narrow fluctuations.

Classes B and C are useful and feasible for many medium and small institutions, and are the best that can be done in most historic buildings. Class D recognises that control of dampness is the only climatic issue.

Building envelopes play an important role in controlling moisture migration into the space. Architectural design should include heavy insulation, and consider possible vapor barriers. Control of openings, window materials, and floor slab insulation are critical in the design. Rainwater runoff design should be considered in the HVAC relationship to collection storage and display areas.

Museums, galleries, libraries, and archives often ask mechanical engineers for "improved climate control" in buildings never designed for such purposes. Conrad (1995) grouped such buildings (and building parts) by their possibilities and limitations into seven categories. In an abridged version of his scheme, Table 10 lists the possible classes of fluctuation control possible for each class of building. Local climate determines which possibility is most likely. For detailed guidance on air leakage and thermal and moisture performance of building envelopes, refer to Chapters 23, 24, and 30 of the 2005 *ASHRAE Handbook—Fundamentals*.

Classification of Climate Control Potential in Buildings

Category of Control	Building Class	Typical Building Construction	Typical Type of Building	Typical Building Use	System Used	Practical Limit of Climate Control	Class of Control Possible
Uncontrolled	I	Open structure	Privy, stocks, bridge, sawmill, well	No occupancy, open to viewers all year.	No system.	None	D (if benign climate)
	II	Sheathed post and beam	Cabins, barns, sheds, silos, icehouse	No occupancy. Special event access.	Exhaust fans, open windows, supply fans, attic venting. No heat.	Ventilation	C (if benign climate) D (unless damp climate)
Partial control	III	Uninsulated masonry, framed and sided walls, single-glazed windows	Boat, train, lighthouse, rough frame house, forge	Summer tour use. Closed to public in winter. No occupancy.	Low-level heat, summer exhaust ventilation, humidistatic heating for winter control.	Heating, ventilating	C (if benign climate) D (unless hot, damp climate)
	IV	Heavy masonry or composite walls with plaster. Tight construction; storm windows	Finished house, church, meeting house, store, inn, some office buildings	Staff in isolated rooms, gift shop. Walk-through visitors only. Limited occupancy. No winter use.	Ducted low-level heat. Summer cooling, on/off control, DX cooling, some humidification. Reheat capability.	Basic HVAC	B (if benign climate) C (if mild winter) D
Climate controlled	V	Insulated structures, double glazing, vapor retardant, double doors	Purpose-built museums, research libraries, galleries, exhibits, storage rooms	Education groups. Good open public facility. Unlimited occupancy.	Ducted heat, cooling, reheat, and humidification with control dead band.	Climate control, often with seasonal drift	AA (if mild winters) A B
	VI	Metal wall construction, interior rooms with sealed walls and controlled occupancy	Vaults, storage rooms, cases	No occupancy. Access by appointment.	Special heating, cooling, and humidity control with precision constant stability control.	Special constant environments	AA A Cool Cold Dry

Source: Adapted from Conrad (1995).

Table 10: Classification of Climate Control Potential in Buildings

5.3 Climate Control Design and Sustainability Guide

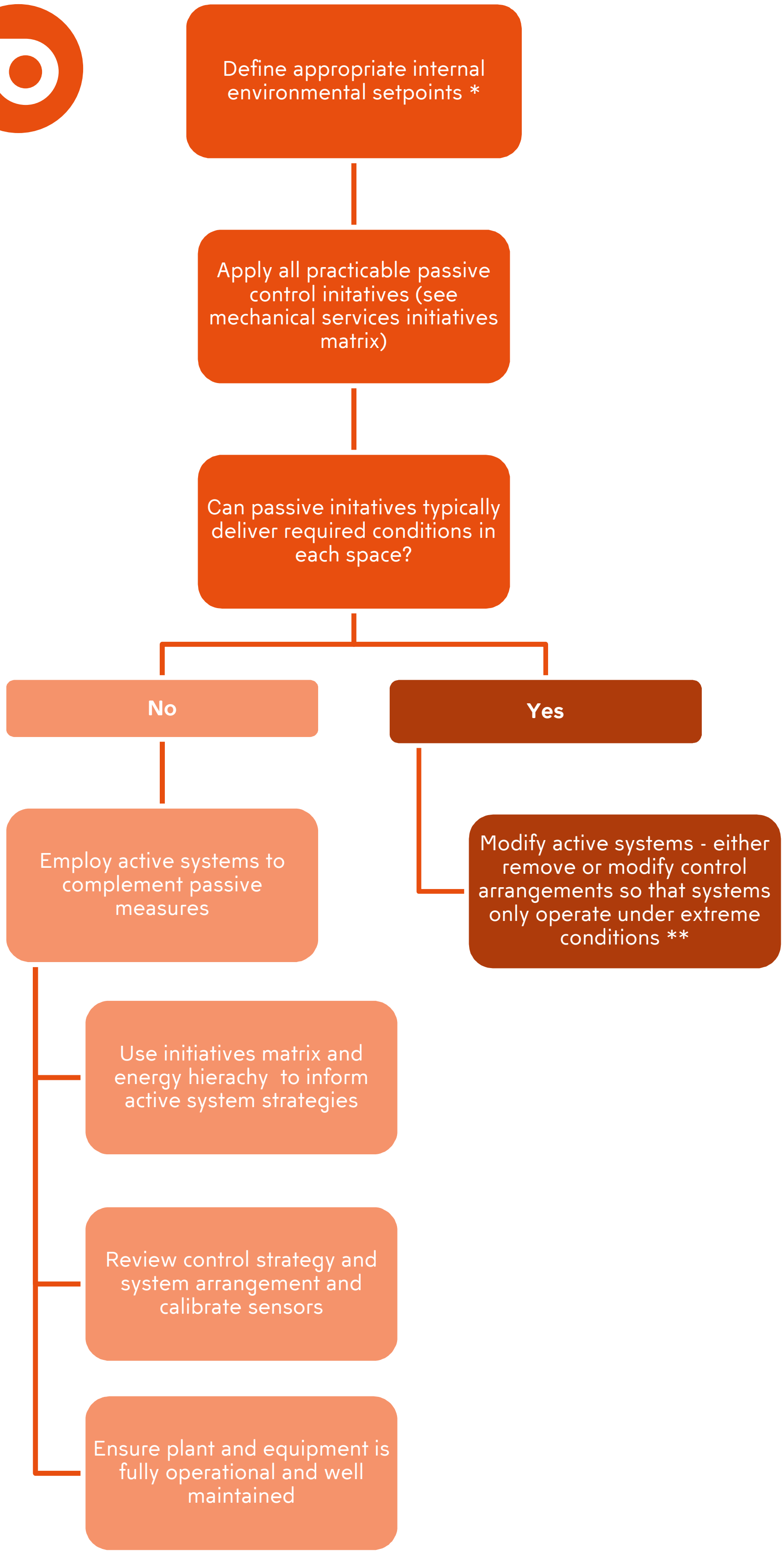

Figure 8: Climate control design and sustainability guide

* Employ relaxed set points wherever possible

** 'Extreme conditions' refer to, for example, external conditions outside of design (i.e. very hot or very cold periods) or extreme occupancy scenarios (blockbuster openings for example). Ensure controls are set up to maintain rate of change limits under all operational scenarios.

*** Passive initiatives represent a discipline all of their own. This guide does not attempt to detail all possible passive initiative appropriate for the museum and gallery environment, rather it seeks to ensure active mechanical systems operate as efficiently and appropriately as possible where they are deemed necessary

5.4 Lighting Sustainability Guide – a checklist

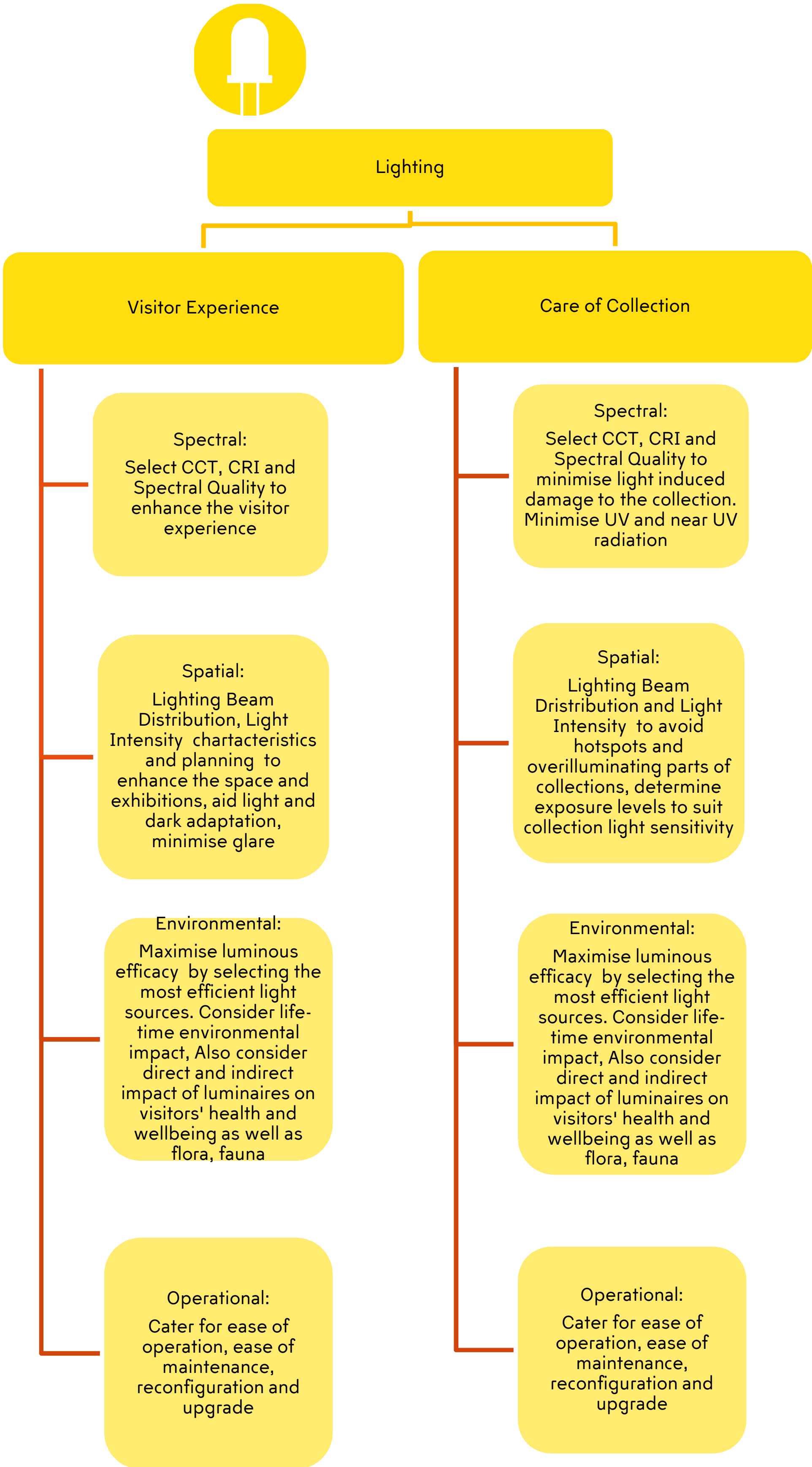

Figure 9: Lighting sustainability guide

6.0 Glossary

Air Exchange
The rate at which outdoor air replaces indoor air is described as the **air exchange** rate. A well-sealed space will have a low air exchange rate and therefore low ingress of unconditioned air that can impact on internal conditions and energy efficiency.

Binning (of LEDs)
During production, even within the same batch, LEDs often vary in colour and intensity characteristics. The differences can be significant and therefore LEDs are measured and delivered to the market in subclasses or groups called bins and this process of segregating LEDs is called binning.

Chilled Water Systems
A system that produces and circulates cold water to heat exchangers over which air is passed in order to cool and draw moisture out of the air.

Colour Consistency
The measure of how close in colour appearance random samples of a light source tend to be. The term refers to the average amount of variation in chromaticity amongst a batch of supposedly identical lamp samples. Generally speaking, the more complicated the physics and chemistry of the light source, the more difficult it is to manufacture with consistent colour properties. This is why consistency is a problem for LED light sources. Different samples from the same batch of LED light sources may exhibit different colour characteristics. To limit this variation, the lighting industry uses a colour consistency system based on MacAdam ellipses (Wyszecki and Stiles, 1982).

Colour Rendering Index (CRI)
A quantitative measure of the ability of a light source to reproduce the colours of various objects faithfully in comparison with an ideal or natural light source. Light sources with a high CRI are desirable in colour-critical applications.

Colour Shift
A measure of the chromatic deviation in colour consistency in comparison to the initial colour appearance of a light source.

Correlated Colour Temperature (CCT)
A specification of the colour appearance of the white light emitted by a lamp, relating its colour to the colour of light from the theoretical reference source of the black body radiator when heated to a particular temperature, measured in degrees Kelvin (K). The CCT rating for a lamp is a general "warmth" or "coolness" measure of its appearance. Lamps with a CCT rating 2500-3500 K are usually considered “warm white” sources, while those with a CCT of 3500-4500 K are considered “neutral white” and those above 4500K are usually considered “cool white” in appearance.

Dead Band
The temperature set point dead band is defined as the temperature range above and below the temperature set point where the system will not take corrective action.

Desiccant Dehumidification
A device that employs a desiccant material to produce a dehumidification effect. The process involves exposing the desiccant material to a high relative humidity air stream, allowing it to attract and retain some of the water vapour and then exposing the same desiccants to a lower relative humidity air stream which has the effect of drawing the retained moisture from the desiccant. A **desiccant** is a hygroscopic substance that induces or sustains a state of dryness.

Dew Point
The dew point is the temperature at which the water vapour in air at constant barometric pressure condenses into liquid water at the same rate at which it evaporates.

At temperatures below the dew point, water will leave the air. The condensed water is called dew when it forms on a solid surface. If air is gradually cooled while maintaining the same moisture content constant, the relative humidity will rise until it reaches 100%. This temperature, at which the moisture content in the air will saturate the air, is called the dew point. If the air is cooled further, some of the moisture will condense.

Dry bulb temperature
Dry bulb temperature is simply the temperature of the air. It does not consider moisture. It is measured in degrees Celsius, degrees Fahrenheit, or Kelvin and can be measured with a thermometer exposed to the air but shielded from radiation and moisture. It is commonly referred to as 'air temperature'.

DX Systems
Direct expansion refrigeration systems. A refrigerant, as opposed to chilled water, is used as the heat exchange medium with the air.

Fading
See Photodegradation.

Hydronic Heating System
A system that produces and circulates hot water to heat exchangers over which air is passed in order to raise the temperature of air.

Illuminance (E)
The amount of light falling onto a surface, measured in lux (lumens per square metre).

Infrared Radiation (IR)
Electromagnetic radiation beyond the red end of the visible light spectrum with wavelengths beyond 760nm.

Just Noticeable Fade (JNF)
A unit measure that is established to measure the fading of objects. Commonly the life of an exhibition artefact is described as 30 Just Noticeable Fades from its original state to a state that is practically unusable.

Kilolux
See Lux.

Law of Reciprocity (for light exposure in preventive conservation)
The inverse relationship between the intensity and duration of light that determines the reaction of light-sensitive material. The law of reciprocity suggests that the light damage is dependent on intensity × time. Therefore, the same damage can result from reducing duration and increasing light intensity, and vice versa. It has been demonstrated that the law of reciprocity may not have a direct ratio between intensity and time, but a more complex equation. However it provides a general framework in order to manage lighting related conservation issues.

Lumen
The measurement unit of luminous flux.

Luminance (L)
Perceived brightness of a surface.

Luminous Efficacy
A measure of energy efficiency of a light source as the ratio of the luminous flux in lumens vs. the electrical power consumption in watts.

Luminous Flux
The total amount of visible light emitted from a light source, measured in lumens.

Lux
The measurement unit of illuminance.

Photodegradation
The degradation of molecules caused by absorption of energy due to exposure to light and ultraviolet radiation.

Rate of Change
The speed at which a variable changes over a specific period of time. In this case, temperature and humidity.

Relative Humidity
Relative humidity is the ratio of the partial pressure of water vapour in an air-water mixture to the saturated vapour pressure of water at a prescribed temperature. The relative humidity of air depends on temperature and the pressure of the system of interest.

It is the percentage of moisture in the air compared to the total amount of water the air can "hold" at that particular temperature. When the air can't "hold" all the moisture, then it condenses as dew.

If air is gradually cooled while maintaining the same moisture content constant, the relative humidity will rise until it reaches 100%. This temperature, at which the moisture content in the air will saturate the air, is called the dew point. If the air is cooled further, some of the moisture will condense (see Dew Point).

Seasonal Adjustment
Movement within a defined set point range that may safely occur over the seasons with a view to saving energy. The rule of thumb is that set points should alter to be as close as possible to average ambient conditions for a particular season (whilst still being within acceptable parameters) in order to save energy.

Set Point
The target temperature and relative humidity values that a control system will try to maintain. May be a range rather than a single point.

Thermal Mass
A concept in building design which describes how the mass of the building provides "inertia" against temperature fluctuations. The greater the thermal mass of a space, the more inertia it has available to help iron out internal temperature fluctuations.

Throttling Range
The temperature set point throttling range is defined as the temperature range for the controller to fully open and fully close the control valve.

Ultrasonic Humidification
A metal diaphragm in a bath of water vibrating at an ultrasonic frequency creates water droplets in the form of a ‘fog’ that are taken into an air stream, increasing its moisture content.

Ultraviolet (UV)
Electromagnetic radiation beyond the blue end of the visible light spectrum with wavelengths ranging typically from 200nm to 400nm.

Vinegar Syndrome
A term used to describe the chemical reaction that goes on during the deterioration of cellulose triacetate film support. When cellulose triacetate begins to decompose, 'deacetylation’ occurs and the acetate ion reacts with moisture to form acetic acid, producing a vinegar odour when a can is opened.

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