Review paper

Environmental conditions for the safeguarding of collections: A background to the current debate on the control of relative humidity and temperature

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Conditions of relative humidity (RH) and temperature within museums and buildings holding collections of cultural heritage objects are often maintained around a strictly controlled set point of about 50 ± 5% RH and 20 or 21 ± 2°C to provide safe, stable conditions for hygroscopic artifacts. It has recently been proposed that these ranges should be relaxed to values that are less energy-intensive to maintain while still being safe for the objects in the collection, with the aim of reducing both carbon footprint and energy use. It is also suggested that conditions should be determined by the needs of individual objects and by the local climate of the region, rather than applying overall values across the museum as a whole. This proposal has led to much discussion within the conservation community. The suggested values, a stable humidity within the range 40–60% RH and a stable temperature within the range 16–25°C for most objects, apart from the most vulnerable, are derived from the results of experimental research on the responses of individual materials to particular conditions of RH and temperature, as well as observations of the behaviour of cultural heritage objects in their own environments and on loan. This paper describes briefly the historical and scientific background to the present discussion.

Keywords: Relative humidity, Temperature, Setpoints, Environmental standards, Environmental conditions, Environmental control, Preventive conservation, Scientific examination of materials, Loan conditions, Display conditions

Introduction

Over the last 30 years or so, many museums and galleries have followed a policy of close control of environmental conditions in order to minimise damage to the objects in their care. A stimulus for the focus on preventive conservation by control of ambient conditions was the publication in 1978 of Garry Thomson's book, *The Museum Environment*, which has remained in print continuously (Thomson, 1978, 1986). His balanced discussion was based on the behaviour of different materials, as far as this was known, and the values for relative humidity (RH) suggested were appropriate for the prevailing climate of the region and the objects in the collection, bearing in mind that some classes of building, such as churches or other historic buildings, might require different solutions. The moisture content, and thus the dimensional stability, of a hygroscopic material like wood is more affected by changes in RH than by temperature, hence the concern shown over the need for a stable, controlled RH. For many types of artifact and for most temperate climates the RH value advised was in the region of 50 or 55%, with a temperature of about 20°C; seasonal adjustments might be necessary. For other climates, values more appropriate to the conditions were suggested (Thomson, 1986, pp. 82–92, pp. 116–24).

Since this time, the technology of air conditioning has improved so that tighter control is possible; in addition, computerised technology now enables gallery conditions to be monitored very efficiently: see, for example, Pretzel (2011). Values of 50 ± 5% for RH and 20 or 21 ± 2°C for temperature (with seasonal adjustments if necessary) have become environmental requirements requested of architects and engineers by many museums, and applied very much more widely than Thomson would have envisaged. They have also been reflected in the conditions specified for loans, although the internationally agreed regulations for loans published by the International Council of Museums (ICOM), in 1974 already gave

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values for RH of 54 ± 4%, with no precise set point for temperature (ICOM, 1974). However, the maintenance of such strict control may require considerable use of energy. There is now a general perception that in the long term such close control is expensive, difficult to achieve in many cases (depending on the efficiency of the equipment installed, the physics of the building, and the climate outside) and unsustainable – 'inelegant', in the words of Thomson, who wrote that future trends should be 'towards simplicity, reliability and cheapness' (Thomson, 1986, p. 267). One should also ask whether or not it is appropriate for every collection in every building in a particular climatic region. Large parts of the world have climatic conditions with very much more extreme ranges of temperature and humidity and widely different average values too, and it may be more important to maintain conditions within the building suitable for the prevailing climate and season, so that other problems, such as condensation or mould growth, are prevented, particularly as a long-established collection may well have become largely acclimatised to the local climate.

Recent events leading to the present debate

What defines a suitable environment for the exhibition and storage of different classes of object? How can this be obtained in a responsible and sustainable way? Will objects suffer if temperature and RH fluctuate more widely than the widely accepted values? In 2008, the first of the International Institute for Conservation of Historic and Artistic Works (IIC) *Dialogues for a New Century* series of roundtable discussions was held at the National Gallery, London, UK, coinciding with the IIC London congress on *Conservation and Access*. This dialogue, entitled *Climate Change and Museum Collections*, took as its subject the implications of climate change and its effects on cultural heritage objects, especially those kept within museums, galleries, houses, and other buildings (IIC, 2008; Saunders, 2008). As a result, the attention of the conservation community was alerted to discussions that were already beginning to take place among museum directors, conservators, scientists, and engineers on environmental conditions within buildings and the safe housing of works of art: the panel comprised representatives of all these interest groups. The public debate begun in London was continued during the 2010 American Institute for Conservation (AIC) annual meeting in Milwaukee, Wisconsin, USA, at the joint IIC and AIC *Dialogue for a New Century, The Plus/Minus Dilemma: A Way Forward in Environmental Guidelines*. Here, the reasons behind the suggested use of broader or narrower ranges of values for temperature and RH were debated by speakers working in museums, conservation institutes, and archives. Some very real concerns were aired, not least the question of whether or not the testing of individual materials, observing their responses at wider or narrower ranges of RH or temperature, was providing answers that are sufficiently convincing or applicable to real, complex objects (IIC, 2010). This point is discussed further below.

In 2009, following consultations with conservators and feedback from discussions held at meetings of the International Group of Organizers of Large-scale Exhibitions, or Bizot Group, the National Museum Directors' Conference (NMDC) of the UK published in draft the *Guiding Principles for Reducing Museums' Carbon Footprint* (National Museum Directors' Conference, 2009). Their aim was to encourage museums to adopt a less energy-intensive approach to the care and loan of collections. The NMDC draft guidelines, subsequently agreed by the European Bizot Group of museums, encourage museums to review their policies on loan requirements, storage, display, air conditioning, and building design to reduce their carbon footprint and energy use. When controlling ambient conditions, the aim should be to respect the conservation needs of artifacts in the collection and also the climate in the region where the museum is situated. Passive methods of control, low-maintenance simple technology, and lower energy solutions should be considered where appropriate. It is well known that different categories of object – wood, stone, metal, glass, paper – have different environmental requirements. The NMDC guidelines accept that more research is necessary into the behaviour of individual objects or groups of object, but have suggested a stable RH in the range 40–60% and a stable temperature in the range 16–25°C as interim guidelines for objects containing hygroscopic materials, RH conditions outside this range being unacceptable for this type of object. Tighter controls are required for more sensitive materials, such as panel paintings, vellum, parchment, and scroll paintings on silk.

These guidelines are comparable with those recommended in recent editions of the general museums, art galleries, libraries, and archives chapter of the *Applications* volume of the *ASHRAE Handbook* (American Society of Heating, Refrigerating and Air-Conditioning Engineers) for chemically stable collections requiring regular access by people, classified as control classes A and B (Michalski, 2009a; Grattan & Michalski, 2010; ASHRAE, 2011). The ASHRAE guidelines are very detailed, in fact, describing the effects on objects if conditions are more variable or more extreme than this, other types of control (for chemically unstable collections or to avoid mould growth or corrosion, for example) and what control is possible in different types of building (ASHRAE, 2011).

Values for RH and temperature similar to the NMDC-suggested values were proposed as guidelines for loans at the meeting of the Association of Art Museum Directors (AAMD) in Indianapolis, USA, in 2010: a set point in the range 45–55 ± 5% RH and a temperature range of 59–77°F, equivalent to 15–25°C. Fluctuations should be minimised (AIC Environmental Guidelines, 2013). The interim guidelines suggested during a meeting of the Bizot Group in Frankfurt in 2012 are essentially those put forward by the NMDC: a stable RH in the range 40–60% and a stable temperature in the range 16–25°C. They also state that there should not be a fluctuation of more than ± 10% RH in a 24-hour period, somewhat similar to the ASHRAE values (Burmester & Eibl, 2013a, p. 2, 2013b, p. 53). Conditions for collections have also been addressed in two recent standards in the UK and Europe. PAS 198:2012, issued by the UK British Standards Institute in response to the NMDC statement, was developed in collaboration with the UK National Archives with sponsorship from other bodies (BSI, 2012); the European standard EN 15757:2010, which is more limited in scope, is concerned with specifications for temperature and RH to limit climate-induced mechanical damage in organic hygroscopic materials (CEN, 2010). These have a slightly different approach in that neither gives precise values for temperature and RH; both suggest that the collection should be considered in the context of its history, climatic conditions, and physical condition. Ranges of values are, however, discussed. The UK standard is comprehensive, considering the effects of light and pollution as well as temperature and RH, and the coverage and range of values indicated is broadly in line with the ASHRAE values. The European standard recommends a middle range of RH, drawing attention to the importance of the historical climate to which the object has become acclimatised.

Not surprisingly, the suggested relaxation in guidelines for museum environmental conditions has caused a considerable amount of debate, most notably in Europe, the USA, and Canada, Australia, and New Zealand – the more temperate regions, on the whole, where the values are perhaps most applicable: the 2010 *Plus/Minus Dilemma* dialogue is only one example. While nobody would disagree with the aims of improving sustainability and reducing the carbon footprint, there are fears that relaxing the RH and temperature requirements for museum and gallery environments might have implications for the stability of sensitive artworks, although each set of guidelines states that certain classes of vulnerable objects require specific and tighter control. The AAMD and Bizot Group interim guidelines also state that the recommendations of conservators should be followed if a work of art is requested for loan. It is on the question of loans, at which these and the NMDC guidelines have been partly aimed, where the discussion is particularly heated, although it is already the case that, if the conditions between the lending and borrowing institutions are at great variance, local control, in the form of a microclimate (display case), may be demanded, or the object is not lent. The recent conference *Climate for Collections: Standards and Uncertainties*, held at the Pinakothek der Moderne, Munich, Germany, in November 2012 addressed the whole issue of suitable and sustainable building environments for cultural heritage collections, from the influence of climate change to conditions in different types of building and the presentation of recent scientific research on the behaviour of real objects in collections, something which has been somewhat lacking in the past (Ashley-Smith *et al.*, 2013). This has been followed by several recent conferences on similar themes: for example, in St Petersburg, Russia, *Museum Climatology is the Basis of Objects of Cultural Heritage Preservation*, held at the State Hermitage Museum; in Berlin, Germany, *Heritage Science and Sustainable Development for the Preservation of Art and Cultural Assets – On the Way to the Green Museum*, held at the Rathgen Research Laboratory, Staatliche Museen, Berlin, Germany; and Paris, France, *Cultural Heritage Conservation Science and Sustainable Development: Experience, Research, Innovation*, organised by the Centre de la recherche sur la conservation des collections, all held during 2013. The debate is lively and several institutions have taken a decision one way or the other or expressed a point of view (Pretzel, 2009; Anderson, 2010; Pes, 2010; Roy, 2011; Burmester, 2013; Burmester & Eibl, 2013a, 2013b; VDR, 2013a, 2013b), but there is as yet no generally agreed consensus.

Historical and scientific background

Underlying the current discussion is a large body of research focused on buildings and their climates, both inside and out; the effects of the climate within buildings on the artifacts they contain; the effects of modifying the internal climate on the building itself; and, significantly, the behaviour of individual materials used to make the artifacts – most of the objects found in collections are composite structures. The earlier history, from the early years of the twentieth century to the 1960s, describes the introduction and development of heating, ventilation, and air-conditioning systems in museum and gallery buildings and the monitoring of the effects this had on the works of art in the collections. Several of the most significant early articles have been collected together in Sarah Staniforth's (2013) recently published

Historical Perspectives on Preventive Conservation and the earlier history has also been usefully summarised by Lambert (2014). A detailed overview, including later developments as tighter control became feasible, but, informed by scientific research, doubts began to emerge as to whether this was actually appropriate or necessary, is given by Brown & Rose (1997). A brief account by the AIC Environmental Guidelines Working Group can be read on the AIC website (AIC Environmental Guidelines, 2013).

Buildings, their environments, and collections

The provision of a reasonable climate for both objects and visitors had become a matter of concern to museums during the nineteenth century (Legnér, 2011; Eibl & Burmester, 2013, Luciani *et al*., 2013). In the early 1890s, the Alte Pinakothek, Munich, Germany, began the installation of a low-pressure steam heating system that not only heated the galleries, but also provided some humidification. This followed the report (dated about 1892) of a commission investigating conditions in other European museums, which recommended that heating should contribute to the preservation of the pictures, with the RH maintained at 50% (Eibl & Burmester, 2013). The Boston Museum of Fine Arts, Boston, USA, introduced humidification in 1908. Here, monitoring the effects of variations in RH on objects in the collection indicated that the value most suitable for paintings and most other works of art was 55–60%, regardless of temperature and the time of year, although this value was too high for armour, on which corrosion occurred unless it was coated with a wax finish; these conditions were also unsuitable for early Egyptian art works (McCabe, 1931). By the 1930s, many collections, particularly in the USA, had some degree of temperature and/or RH control, and museums in Europe were also investigating the possibilities of air conditioning or other forms of environmental control (Keeley & Rawlins, 1951; Legnér, 2011; Eibl & Burmester, 2013).

Perhaps, the best known historical example of the benefits of a stable climate for works of art is that of the storage during the Second World War of the paintings of the National Gallery, London, UK, in the Manod slate quarry near Blaenau Ffestiniog, Wales, from 1941 to 1945 (Davies & Rawlins, 1946). Here, stable conditions of 58% RH (chosen on the basis of work carried out earlier, mentioned below) and a temperature of 17°C were maintained by heating alone, and the cracking, flaking, and blistering of paint that had had to be treated regularly in the uncontrolled environment of the National Gallery in the years before the war did not occur. Once returned to the unconditioned gallery rooms after the war, however, the warping of panels and damage to the paint re-occurred and the need for conservation treatment resumed. Following a recommendation from the Weaver Committee in 1947, air conditioning of the rooms began to be introduced in 1950 (Keeley & Rawlins, 1951; Padfield, J. *et al*., 2013). Pre-war research carried out by the Forest Products Research Laboratory on seasonal variations in the moisture content of blocks of fir, oak, beech, and elm (woods used in European panels and other art works) placed in gallery rooms indicated that the average moisture content throughout the year was about 11%, compared with dry weight. This is equivalent to an optimum RH value of 55–60% for this London building; control around this point was thus chosen (Keeley & Rawlins, 1951). It has subsequently been pointed out that, although these conditions were stable, it was not known if they were optimal for panel paintings: no comparative research was carried out on other sets of stable values for RH and temperature (Michalski, 1993; Erhardt *et al*., 2007). Subsequently, however, RH values around the 50–60% mark came to be widely applied. A survey of museums published in 1960 revealed that most preferred a range of RH values around 40–70%, mostly within or overlapping the 50–60% range, 50% being recommended to avoid desiccation of materials such as parchment, 60% at the upper end to avoid mould growth (Plenderleith & Philipott, 1960). These values were, however, difficult to achieve in cold climates and could contribute to damaging condensation within the building housing the collection (Erhardt *et al*., 2007). As in many cases, the homes of collections are themselves historic buildings this was, and is, a serious issue (Schulze, 2013).

By the 1990s, it was recognised that closely controlled RH in museums was not necessarily easy to achieve; air conditioning was difficult to accommodate in historic buildings and it was not cheap to run. As Thomson (1986, p. 268) had also recognised in the second edition of his book, historic buildings, the homes of many collections worldwide, often needed a different approach and account also needed to be taken of local climatic conditions (Kerschner, 1992; Oreszczyn *et al*., 1994; Staniforth *et al*., 1994). The National Trust (for England), for example, uses a system of conservation heating in their houses (which are mostly closed to the public during the winter) whereby RH is controlled to about 60% by heating the rooms to a temperature 5 or 6°C above that outside (to a maximum of 18°C, 22°C in summer) by the use of a humidistat set to a predetermined value: if the RH rises above this value, the heating is switched on until it falls. Considerable energy savings can be made this way (Staniforth, 2006; Blades *et al*., 2011). Scientists and conservators were also aware that, for objects lent by one institution to another for temporary exhibition or a longer loan, there were instances when the conditions provided by the borrowing institution did not match those required by the lender, but the returning objects did not seem to have suffered any damage attributable to this. This suggested that the materials of these objects were rather more tolerant to apparently slightly inappropriate conditions than generally supposed (Ashley-Smith *et al.*, 1994). More broadly, the assessment of risks to collections from inappropriate conditions and other agents could enable priorities for the management of preventive conservation to be recommended (Waller, 1994).

In recent years, many case studies describing the control of the environment within a range of buildings from churches to archival stores have appeared. The aim has generally been to reduce damaging fluctuations of RH and temperature, close control often being impractical, while maintaining an appropriate level of human comfort; compromises and creative solutions are often necessary (Camuffo *et al.*, 1999; Padfield & Larsen, 2004; Hioki, 2008). The problems are particularly marked for buildings in sub-tropical or tropical regions with high RH (Krüger & Küster de Paula Carvalho, 2005; Broecke, 2007). Suggested solutions to these problems were among the subjects presented at the Getty Conservation Institute Roundtable on *Sustainable Climate Management Strategies*, Tenerife, Canary Islands, 2007, organised as part of the Alternative Climate Controls for Historic Buildings project (2003–2010) and available online (Boersma, 2009; Maekawa, 2009). Some of the most interesting and imaginative recent work on the control of environments within buildings was presented at the 2007 Copenhagen conference on *Museum Microclimates* (Padfield & Borchersen, 2007), and more recently at the 2012 *Climate for Collections* conference (Ashley-Smith *et al.*, 2013). It is impossible to draw attention to all these studies in the space available, but one method being studied by the National Museum of Denmark and others is the use of the architecture itself to control the environment within storage buildings (for archives, for example) by means of humidity buffering in the walls, summer dehumidification by solar power, and other devices (Ryhl-Svendsen *et al.*, 2011, 2013; Klemm, 2013; Padfield, T. *et al.* 2013). The collection itself may also provide some humidity buffering, particularly in the case of paper-containing archives. This low-energy control is easier to achieve if staff and visitor comfort is not a factor.

Scientific examination of materials and artifacts

Erhardt *et al.* (2007) comment on how little experimental evidence on materials, apart from a limited amount on wood, supported the then generally accepted values for RH and temperature, even up to the publication of *The Museum Environment* in 1978. During the late 1980s and 1990s, research carried out at the Smithsonian Institution, Washington DC, USA, and the Canadian Conservation Institute (CCI), Ottawa, Canada, provided information on the mechanical, physical, and chemical behaviour of individual materials in response to changes in temperature and RH: by how much these temperature and RH values could vary, and how rapidly, before the material being tested failed and whether or not the reactions – mechanical, physical, or chemical – of the material to these environmental changes were reversible. The effects on degradation processes and of ageing on physical properties were also observed. Computer modelling was used to predict the effects of environmental changes and failure rates. The materials studied included wood, animal glues, and other adhesives (also mixed with suitable fillers as in panel painting grounds), cast paint films, cellulose, and canvases (most samples fairly recent in date); observations were also gathered on glass, metals, minerals, stone, and other materials (Mecklenburg & Tumosa, 1991; Michalski, 1991, 1993; Erhardt & Mecklenburg, 1994, 1995; Mecklenburg *et al.*, 1994, 1998; Erhardt *et al.*, 2007). This very substantial body of work confirmed that, for most materials, RH is a more significant factor than temperature, except in the case of chemical degradation which is usually temperature-dependent. It suggested that many of the tested materials found in an aged condition in objects of cultural heritage might be able to withstand greater fluctuations in RH than had previously been thought, although in practice this depends on the previous history of the object, its construction, and its condition (Erhardt & Mecklenburg, 1994). Lowering the temperature also reduces the rate of chemical degradation in vulnerable materials as long as the consequent increase in RH does not cause damp conditions that promote other forms of damage such as mould growth (Michalski, 2002). As a result of this research, the recommendations for RH and temperature for the Smithsonian Institution were broadened to 45 ± 8% RH and 21 ± 4°C, fully discussed in Mecklenburg (2007a, 2007b). The suggested broader guidelines (40–60% RH, a stable temperature of 16–25°C) proposed for collections, and the current ASHRAE guidelines derive from this work. These are also the present CCI recommendations (Michalski, 2009b, 2009c; Grattan & Michalski, 2010).

The results of this research have caused some controversy, particularly among conservators and heritage scientists caring for easel paintings, polychromed sculpture, furniture, and wooden artifacts in general as the response of any composite object, particularly one of great age, is likely to be rather more unpredictable than the response of what is assumed to be its most vulnerable constituent. Not only is the construction of a panel painting or a piece of furniture complex: it may have been restored and repaired with a variety of materials (Brewer & Forno, 1997; Brewer, 1998; Young *et al.*, 2002; Phenix & Chui, 2011). The modelling of the ageing of canvas paintings is also not straightforward (Young & Ackroyd, 2001). However, informative scientific research on cultural heritage objects themselves, alongside that on modelled systems, is beginning to appear (Watkinson & Tanner, 2008; Luxford *et al.*, 2010, 2013; Garside & Knight, 2011; Kozłowski *et al.*, 2011; Bratasz, 2013; Gong *et al.*, 2013). Recent research on a polychromed altarpiece in an Italian church, for example, demonstrated the effects of the seasonal cycles of temperature and RH and, more damagingly, short-term winter heating. Following external changes in RH, while moisture exchange took place continually and rapidly from the outermost few millimetres of the painted wood, moisture content gradients developed in the more massive areas, where the uptake or release of moisture, and thus dimensional change, was very much slower. This led to stress development and ultimately cracking in the outermost region (Bratasz *et al.*, 2007).

A recent concept is that of 'proofed fluctuation', the largest RH or temperature fluctuation to which the object has been exposed in the past (or simply the lowest and highest past values for RH and temperature of the past), assuming that collections acclimatise to their surroundings. It is suggested by the author that the risk of further mechanical damage from fluctuations smaller than this value is extremely low and, as long as future climate conditions do not exceed the range defined by past conditions, further mechanical damage is unlikely (Michalski, 2009a, 2009b, 2009c). This assumes, however, that no interventive conservation treatment to the object has taken place; in addition, it should be noted that the historic climatic conditions to which the object has been subjected are usually not known precisely.

Conclusion

Keeping artifacts, particularly those composed of hygroscopic materials, in a stable environment has been shown to be beneficial: the objects have remained in good condition over the period of time in which their environment has remained stable and controlled. However, it has also been found that similar objects, kept under apparently less than ideal and fluctuating conditions, to which they have acclimatised, do not seem to have suffered. Many factors contribute to the discussion of whether a collection, or an individual art work, should be kept under more or less strict climatic conditions, or whether it will suffer as a result of change in these conditions if it travels for temporary exhibition elsewhere. The reduction of unsustainably high-energy costs and a museum's carbon footprint is to be encouraged, and relaxing the control of the values for RH and temperature may contribute to this if it can be done without damage to the collection. Much has been learnt from the study of buildings and their behaviour and the materials comprising the artifacts; what is lacking is further observation of the behaviour of the objects themselves. As cultural heritage objects are usually complex, composite structures and each one is individual in its construction and history, this research may be challenging, but is also necessary.

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