

PROCEEDINGS OF THE SMITHSONIAN INSTITUTION

SUMMIT ON THE MUSEUM PRESERVATION ENVIRONMENT

EDITED BY SARAH STAUDERMAN AND WILLIAM G. TOMPKINS



Smithsonian Institution
Scholarly Press

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A SMITHSONIAN CONTRIBUTION TO KNOWLEDGE



**Smithsonian Institution
Scholarly Press**

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Letter from the Secretary

Since its inception in 1846, the Smithsonian Institution has been defined by its priceless collections that represent the collective memory of our nation. They help researchers and thousands of scientists and scholars at home and abroad understand life on our planet. They are the lifeblood of the Institution. And as we strive to remain a vital learning resource in a digital age, both for the American people and the citizens of the world, it is crucial that we use every tool at our disposal to protect these revered treasures.

This effort begins with caring for the buildings in which our collections are held. It is why we are investing millions of dollars in improving our facilities, making them more resilient, more sustainable, and more able to provide optimal conditions to preserve the collections. The varying ages of our buildings present us with challenges. But so do the incredibly diverse items in our collections, from the 4.5-billion-year-old Allende meteorite to newborn animals, from the mammoth space shuttle *Discovery* to tiny samples of frozen tissue and DNA, from timeless portraits in oil to artworks that exist only as pixels and data.

The Smithsonian engages a full range of subject experts to determine the best ways of protecting our collections, and in doing so we improve communication and collaboration among the critical stakeholders who design, establish, and maintain preservation environments, from the building envelope to microclimates. Today, the Smithsonian and the museum profession stand at a critical crossroad. It is time to reassess past standards, practices, and behavior established in another era. Working together, we can build on current scientific research, first-hand experience, and risk assessments to achieve an optimal and sustainable environment within our respective institutions and collections.

We take our role as environmental stewards seriously, making sustainability a centerpiece of our preservation strategy. Sustainable approaches not only minimize the human impact of our activities on our environment but also reduce long-term costs and allow better use of scarce funds to serve collection needs. As this is being written, Smithsonian conservators and engineers are working to test seasonal temperature and relative humidity setbacks at our Museum Support Center in Suitland, Maryland. Permitting small seasonal shifts in set points saves energy by reducing cooling loads in the summer months and heating loads in the winter months. This is all accomplished while staying within acceptable temperature and humidity collections preservation specifications.

Our engineers have also been modifying the existing museum air handling unit sequence of operations to reduce the amount of outside air that enters a museum during unoccupied hours. The benefits of this are twofold: it allows for a large reduction in energy usage, resulting in substantial cost savings, and it limits air contaminants and temperature and humidity

fluctuations, helping to further preserve collections. In all, more than 18 construction projects underway across the Smithsonian, many of which address spaces that house collections, are planned to attain energy efficient LEED status.

John Quincy Adams, the sixth U.S. president and a staunch supporter of the Smithsonian's creation, once noted that "to furnish the means of acquiring knowledge . . . prolongs life itself and enlarges the sphere of existence." That is at the heart of what museums do for their communities, and collections underlie our ability to achieve this lofty goal.

Preserving our cultural and scientific heritage and managing the museum environment to ensure the long-term preservation and accessibility of collections is a collective responsibility shared by a variety of professional disciplines. The proceedings of the Smithsonian's 2013 Summit on the Museum Preservation Environment offer a wealth of information to stimulate dialogs that will help establish and implement strategies needed for the future. I thank the Summit Planning Committee, especially Sarah Stauderman, Mary Rogers, and Bill Tompkins, for their leadership and hard work and all of the contributing speakers who made the Summit on the Museum Preservation Environment such a huge success and this publication possible. I think this resource will provide valuable guidance for museums around the world.

*G. Wayne Clough
Secretary of the Smithsonian
December 2014*

Foreword

Nancy Bechtol and Scott Miller

The Smithsonian Institution held a public Summit on the Museum Preservation Environment in March 2013 as part of its commitment to holistic and collaborative management of its collections. We expect this proceedings volume to be the new baseline for the understanding of the museum preservation environment, and we hope that it catalyzes both implementation of what we know and further research to advance the field.

Ensuring the long-term preservation of the collections entrusted to our care through the development of sustainable strategies is a priority for the Smithsonian. Indeed, collections and their stewardship are core activities of most museums. Collections provide the intellectual base for scholarship, discovery, exhibition, and education, as well as documenting previous research, and, especially in science, allow the evidence-based validation of research. Smithsonian collections are national and global resources accessed by millions of visitors and researchers each year who use both traditional methods and new technologies to explore subjects from aeronautics to zoology. New technologies such as DNA analysis and hyperspectral imaging for research and visualization raise opportunities to extract new layers of information out of old collections but also raise new challenges in preserving the full range of physical properties of the objects.

In 1846, Congress directed the Smithsonian to create a collection of “objects of art and of foreign and curious research, and . . . of natural history.”¹ More recently, Congress recognized the value of the federal scientific collections as vital to America’s “scientific enterprise.”² U.S. government policy is now “committed to ensuring the proper management, preservation, security, and ethical use of Federal scientific collections to inform scientific research and maintain the Nation’s legacy of exploration and discovery,” and “scientific collections provide an essential base for developing scientific evidence and are an important resource for scientific research, education, and resource management. Scientific collections represent records of our past and investments in our future. Policies and procedures for maintaining, preserving, and developing Federal scientific collections while also increasing access to those collections for appropriate use are, therefore, central to their value.”³ A few of the major global challenges for which collections provide critical evidence include climate change, spread of invasive species, epizootic disease, loss of biological diversity and cultural heritage, and their impact on global ecosystems and society.

Strengthening stewardship of our collections is fundamental to the Smithsonian’s mission, but the volume, characteristics, complexity, and age of our collections and the variety of discipline-specific care standards present great challenges. Therefore, we have taken an interdisciplinary approach and promoted dialogue about the preservation environment that includes the full range of required subject specialists—conservators, curators, scientists, architects, engineers, librarians, archivists, registrars, collections and facility managers, and museum administrators.

The museum and collections community needs to commit to furthering our understanding of the preservation environment and improving communication and collaboration among the critical stakeholders who share responsibility for designing, establishing, and maintaining the collections environment from the building envelope to microclimates. As a profession, we must take a pragmatic and responsible approach in carrying out our stewardship responsibilities, applying common sense and balancing preservation requirements, building fabric, and systems capabilities. The business of preserving things “forever” is not easy. Significant financial investments are required for construction and long-term maintenance, and we need to make those investments in the most responsible and sustainable way possible.

With the rise of exciting new options in green building technologies, we need to strike a balance in addressing collections preservation and green building goals. The need to reduce our greenhouse gas emissions and the increasing costs for energy have placed increasing demands to control our temperature and humidity only to the levels that are actually required by our collections. By working collectively, we can figure out these exact parameters and develop new standards for specific collection types.

Two themes emerged from the discussions and are documented in this volume. One is the importance of collaboration in establishing and maintaining preservation environments because no single discipline has the full perspective and responsibility. The other is the need to separate standards based on urban legend or tradition from evidence-based decision making. As acknowledged in many of the papers, Dr. Marion Mecklenburg, now retired from the Smithsonian Museum Conservation Institute, and his international team of collaborators were trailblazers in producing scientific evidence that many cultural heritage materials are much more resistant to temperature and humidity changes than had been generally thought.

The Smithsonian has made significant progress at raising the level of collections care, storage, and digitization, thereby improving collections accessibility. Addressing our collections needs in a systematic and cost-effective manner depends on a pragmatic, strategic, and integrated approach through collections assessments, long-term planning, and prioritization, taking into account physical care, digitization, intellectual content, preservation environment, and a series of other issues regarding the quality of collections space. This summit and the proceedings are a product of our Collection Space Planning Initiative, a multiyear highly collaborative and interdisciplinary effort conducted by collections and facilities management staff with a pan-Institutional steering committee. The planning initiative is described in the 2014 report *Securing the Future for Smithsonian Collections: Smithsonian Collections Space Framework Plan*, which reflects a new era of collaboration across professional disciplines at the Smithsonian.⁴

Along the way, we have found that the diversity of our disciplines, when all brought together to serve the greater good, can make it a challenge to communicate effectively for the betterment of our preservation environments and ultimately the objects they protect. Sometimes just finding a common vocabulary is a challenge! We need to share foundational knowledge on current thinking and research regarding environmental impacts on preservation, approaches to risk and standards, and balancing preservation and sustainability—knowledge

on which we can build our future conversations about more efficient and effective ways of working together.

Management of the preservation environment is a responsibility shared by collections, exhibition, and facilities staff. They need to be empowered to work together, communicate, and collaborate across their respective disciplines to ensure a sustainable strategy for the future of the world's cultural and scientific heritage and the global environment.

Finally, we thank the Summit Planning Committee, especially Bill Tompkins, Sarah Stauderman, and Mary Rogers, for their leadership and hard work in convening both the conference and the proceedings.

Notes

1. 20 U.S.C. § 50 (1846).
2. 42 U.S.C. § 6624 (2010).
3. Office of Science and Technology Policy, "Improving the Management and Access to Scientific Collections" (memorandum for the Heads of Executive Departments and Agencies, Executive Office of the President, Office of Science and Technology Policy, Washington, D.C., March 20, 2014).
4. Smithsonian Institution, *Securing the Future for Smithsonian Collections: Smithsonian Collections Space Framework Plan* (Washington, D.C.: Smithsonian Institution, 2014).

Introduction

Sarah Stauderman and William G. Tompkins

This publication presents the proceedings of the Summit on the Museum Preservation Environment, held at the Smithsonian Institution in March 2013. The purpose of the summit was to start a conversation over a gap in collections management policy at the Smithsonian, namely, that Smithsonian collections and facilities management staff desire a written standard and best practices document for the management of environments in spaces where collections are housed. They acknowledged that the controlled environments of many of the Smithsonian's collections were based on commonly held notions of environmental "standards" (i.e., 70°F/45% RH with \pm variations) that are at odds with current and even historical research findings and not understood by stakeholders to be the final and best preservation environment for all collections. They further recognized that establishing environments for long-term preservation of collections must take into account mandated and socially responsible energy savings and sustainability goals.

The context for the summit laid in the Smithsonian's interest in improving its collections management practices and also in a growing international interest in the cultural heritage field to improve the preservation environment for museum, archival, and library collections. The Smithsonian approach to discussions about the preservation environment, as shown at the summit, differs from some others in that its emphasis is on the collaborative engagement necessary among cultural heritage professionals and the description of an iterative process of determining the best and most realistic environment for collections, not to dictate set points. The Smithsonian's contribution to the wider discussion is to lay a framework for developing procedures for establishing communication between all stakeholders of the preservation environment.

In setting out to host a conversation about the preservation environment, the Smithsonian's goals for the summit were far-reaching:

- to familiarize Smithsonian staff with the current research on the role of environmental factors in the long-term preservation of collections
- to itemize the best collaborative approaches to establishing environmental parameters
- to provide a forum for discussion and adoption of a new Smithsonian Institution policy document on the preservation environment

A fourth goal emerged during the summit discussions, which was that the Smithsonian Institution should share its deliberations, resources, and perspective with the international collections care and cultural facility management communities.

To achieve these goals, a Summit Planning Committee consisting of Smithsonian conservators, collections managers, and facilities engineers conceived of the summit's two-part program. The first part (Day One), open to Smithsonian and non-Smithsonian staff and allied professionals,

was devoted to learning and understanding the issues; the second part (Day Two), open to Smithsonian collections and facilities management staff, was devoted to sharing knowledge, experiences, and challenges in adopting environment policy for collections at the Smithsonian.

World-renowned preservation scientists, researchers, and engineers who could capture the attention of an audience that would consist of seasoned museum workers from diverse professional orientations were invited to speak at the summit. To make the speaker selections, publications were reviewed, and conference proceedings were examined as the committee considered the qualifications and reputations of the potential speakers. The committee sought to invite international expertise and to be sensitive to issues of controversy that have been raised by practitioners in this area. The committee sought experts who could tell the story of the preservation environment and promote collaboration in the field. The members of the Summit Planning Committee and invited speakers are pictured in Figure 1.

Additionally, the Summit Planning Committee developed a draft “Declaration on the Collections Preservation Environment,” which was used on Day Two as a discussion guide,



FIGURE 1. Members of the Summit Planning Committee and invited speakers following Day One of the Summit on the Museum Preservation Environment program, March 5, 2013, at the National Museum of the American Indian, Rasmuson Theater. Front row (left to right): Mary Rogers, Kendra Gastright, Jane Passman, Wendy Jessup, Kathryn Makos. Second row (left to right): Richard Barden, Scott Rosenfeld, Luanne Greene (speaker), Cecily Grzywacz (speaker), Fiona Cousins (speaker), Sarah Stauderman, Catharine Hawks, Paula DePriest. Third row (left to right): William Tompkins, Ann Trowbridge, Robert Waller (speaker), Jonathan Ashley-Smith (speaker), David Hawk, Michael Henry (speaker), Paul Tintle, James Reilly (speaker), Stefan Michalski (speaker). Not pictured: Michael Carrancho, Susan Cary, Malcolm Collum, Kathy Ernst, Justin Estoque, Joshua Gorman, Gail Joice, and Sharon Park.

providing opportunities for Smithsonian staff to confer on ways to clarify stakeholder roles, responsibilities, and expectations as related to the preservation environment. The revised declaration is included in the Guides and Resources section of this volume.

Despite a delay in holding Day Two due to winter weather, the summit was declared a success by those who participated on one or both days. A heavy snowfall closed the federal government, including the Smithsonian, on March 6th, requiring Day Two to be rescheduled. Despite the weather, summit speakers and planners pictured in Figure 2 were invited to meet for breakfast to discuss the draft declaration, building on the energy and enthusiasm of Day One. We heard commendations on the enlightening presentations, the opportunities created for participants to have a dialogue about this important topic, and even the invited speakers' collective wit. What cannot be underestimated as a factor in the success of a program such as this summit was the great diversity of disciplines represented by the participants and the feeling of interconnectedness it lent to the program. Not only were our subject experts describing how imperative it is to involve all the stakeholders in discussions about the preservation environment, but participants could look left and right down the aisles and see those other stakeholders, their colleagues, hearing the same information and devoting time to learning about



Photo courtesy of William Tompkins.

FIGURE 2. “Pete’s Diner Declaration.” Invited Summit speakers and planners meet for breakfast at Pete’s Diner on Capitol Hill on March 6, 2013 after a snowstorm closed the Smithsonian, requiring Day Two to be cancelled and rescheduled. Pictured: (left to right): Stefan Michalski, James Reilly, Robert Waller, William Tompkins, Jonathan Ashley-Smith, Michael Henry, Sarah Stauderman, Cecily Grzywacz.



FIGURE 3. Summit participants at Day One, March 5, 2013, at the National Museum of the American Indian, Rasmuson Theater.

this important topic. Participants left knowing that the profession stands at a critical crossroad where it can distance itself from past standards, practices, and behavior and lay the foundation for the implementation of sustainable approaches and interdisciplinary collaboration and decision making in designing, maintaining, and managing the preservation environment. Summit participants of Day One are pictured in Figure 3.

The resources in this publication can serve as the basis of an intellectual framework onto which the reader can apply specific collections' histories and vulnerabilities, local climate, and local system capabilities, providing support for decisions about the appropriate preservation environment. This framework is not going to tell you what to do; it is not prescriptive. However, valuable lessons learned at the summit and described in this publication should inform one's decision making:

- When it comes to the preservation environment, one size does not fit all for performance specifications or for HVAC systems.
- A rich and deep understanding of collections vulnerabilities and purpose within a collecting context must be attained by custodians.
- A history of research has lead us to this point, but more review and research is needed, especially dedicated discussions on subject areas such as light, pollution, temperature, humidity, and air exchange.
- Standards are no longer prescriptive but a component part of an integrated philosophy and collective decision making based on risk assessment; therefore, collaboration

among conservation, collections management, and facilities management disciplines is imperative.

- Stewardship of collections is achievable alongside stewardship of energy and natural resources.
- A need to be more skilled and nuanced in the approach to and understanding of the preservation environment.

The Presentations section of this publication contains edited transcripts of the presentations provided by the summit's invited subject experts. The Guides and Resources section contains information that we hope contributes to the cultural community's preservation environment and collaboration tool boxes:

- a discussion and exercise guide listing questions we asked ourselves on Day Two of the summit, when we examined our current working processes and resources available to address this topic and task
- selected resources
- the summit program
- the "Smithsonian Institution Declaration on the Collections Preservation Environment," which is our resulting high-level guiding document that ensures the many professional disciplines collaborating at the Smithsonian are working toward common goals

We thank the members of the Summit Planning Committee for their dedication and vision in developing the summit program and this publication, Smithsonian leadership for supporting this wide-reaching initiative, and Smithsonian staff in all corners of the Institution for contributing to this important dialog. We thank Katharine Untch for preparing the discussion and exercise guide section and Valerie Greathouse, Reference Librarian, Information & Communications, at the Getty Conservation Institute, for assistance with compiling the resources list in that guide.

Although the "Summit on the Museum Preservation Environment" and this publication were made possible by numerous contributors, we especially acknowledge the immense contributions of Mary Rogers who worked diligently to help facilitate this initiative from beginning to end. The Summit Planning Committee and speakers are indebted to Mary for her exceptional project management and editorial skills, steadfast enthusiasm and compassion, and unwavering professionalism and dedication. Mary, we could not have accomplished this without you!

Last, we extend our gratitude to our distinguished panel of summit speakers and contributors to this volume, who, through their tireless provision of knowledge to forums, publications, and serendipitous discussions, continue to lead the way and the charge toward a more reasoned and sustainable approach to the preservation environment.

Summit Planning Committee, 2012-2013

- Chair: Sarah Stauderman, Assistant Director for Collections Care, Smithsonian Institution Archives
- Richard Barden, Preservation Manager, National Museum of American History

- Michael Carrancho, Deputy Director, Engineering and Design Division, Office of Planning, Design and Construction, Office of Facilities Engineering and Operations
- Susan Cary, Registrar, Archives of American Art
- Malcolm Collum, Chief Conservator, National Air and Space Museum
- Paula DePriest, Deputy Director, Museum Conservation Institute
- Kathy Ernst, Social Science Analyst, Office of Policy and Analysis
- Justin Estoque, Assistant Director for Operations, National Museum of the American Indian (formerly)
- Kendra Gastright, Director, Office of Facilities Management and Reliability, Office of Facilities Engineering and Operations
- Joshua Gorman, Collections Manager, Anacostia Community Museum
- David Hauk, Supervisory Electrical Engineer, Energy Management, Office of Facilities Management and Reliability, Office of Facilities Engineering and Operations (formerly)
- Catharine Hawks, Conservator, National Museum of Natural History
- Wendy Jessup, consultant for preventive conservation, Wendy Jessup and Associates
- Gail Joice, Collections Manager, National Museum of the American Indian
- Kathryn Makos, Industrial Hygienist, Office of Safety, Health and Environmental Management (retired)
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- Scott Rosenfeld, Lighting Designer, Smithsonian American Art Museum
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- William G. Tompkins, Director, National Collections Program
- Ann Trowbridge, Associate Director for Planning, Office of Planning, Design and Construction, Office of Facilities Engineering and Operation

PRESENTATION

Climate Guidelines for Heritage Collections: Where We Are in 2014 and How We Got Here

STEFAN MICHALSKI

ABSTRACT. The history of museum climate guidelines is developed through three overlapping strands: awareness of problems, doing something about them, and the slow development of the science. Topics covered are nineteenth-century discoveries of climate issues; the history of passive RH control and its science, the emergence of mechanical systems, and the logic of best available technology; the emergence of stringent specifications; an era of relaxation; the emergence of current specifications; a critical history of the science; and the five errors of argumentation about specifications. The conclusions offer a brief recipe for action for institutions making decisions on this topic.

Introduction

Three threads run through the history of museum climate issues, each starting at different times. First came the awareness, long before museums existed, that some deterioration processes are determined by climate. Common word pairings such as damp with decay and drying with cracking demonstrate this awareness. Second came the concern to do something about the problem, systematized centuries ago in terms of good housekeeping, natural ventilation, and sealed enclosures for precious things. In the twentieth century such passive methods gave way to reliance on active mechanical systems. In the twenty-first century, as we shall see, the pendulum has swung back—sustainability is driving a search for the best of old and new methods. The third thread, and the newest, has been the slow development of a conservation science sufficient to answer the following question: What control, if any, do collections really need?

I am not an outsider to the history of these issues, but I have tried to be evenhanded. I think there has been a tendency until very recently not to do the hard work of finding relevant knowledge already created in other disciplines. In its absence, specifications were created on the basis of “best available technology,” which was understandable, but then this provisional reasoning hardened into dogma and, worse, pretended to reflect collections needs. I believe that our last error, now that the science has grown respectable, has been to hope that science alone can answer the question of real-world specifications, that is, decisions. It cannot, not in other fields of risk management and not in ours.

The benchmark history of museum climate specifications, mechanical systems, and building design, including important sources from the non-English world, is the Ph.D. thesis by Luciani (2013). For a shorter critical history of English language sources, see the paper by Brown and Rose (1997). For a survey of the last few years of argumentation and implementation around the world, see Bickersteth (2014). For a concise history relevant to image archives, neglected in the “museum climate” debate, see Image Permanence Institute (2010) and Reilly (this volume).

Nineteenth-Century Discoveries by Interested Chemists

By the late nineteenth century, the paint chemist Church (1872:247) provided a good, albeit incomplete, understanding of the central issue of museum climate control: “If a stream of warm and dry air enters a gallery . . . the canvases, frames, and panels become altered in shape and size each day. . . . Thus the colored films . . . are submitted to an injurious strain, which may end . . . in a multitude of minute fissures, and the final flaking off of portions of the paint.” Most of the relevant causal chain is in place: heating systems in winter cause low RH, which causes

dimensional response of the materials, which causes strain beyond the material's limits, which causes fracture and delamination. The only important omission in this causal chain is that the climate response of the coating layers matters as much as, and often more than, the response of the support layers. It would take a full century before the Smithsonian researcher Mecklenburg (1982) identified this omission.

The nineteenth century also saw understanding of the role climate played in chemical deterioration. In a major study of light damage for the National Gallery of London, Russell and Abney (1888) demonstrated that high RH accelerated light damage and that most of the colorants they studied were much less affected by light when both humidity and oxygen were removed. By the turn of the century, the German chemist Rathgen, known as the father of conservation science, discovered that the rapid corrosion of recently excavated bronzes—called bronze disease because it was believed to be caused by microbes—could be stopped by very low RH (Rathgen, 1905).

In summary, by the end of the nineteenth century, the qualitative aspects of museum climate concerns were fully in place; that is, chemical decay is slower with lower RH and lower temperature, climate fluctuations can lead to cracks and delamination, and decay (mold) requires high RH. The only question remaining was exactly how much damage at what conditions?

The Discovery, Rejection, and Resurgence of Passive RH Control by Enclosures

The nineteenth-century chemists advising museums about climate issues not only elucidated the damage phenomena, they also developed localized means of control. Church (1890:312) stated, “The covering of an oil picture with glass, whatever objections may be urged against it from an artistic point of view, certainly secures the protection of its surface . . . the back of pictures, especially of those painted on canvas, is often forgotten, yet excess of moisture and deleterious vapours and gases often enter from behind.” This was not a perfect understanding since he conceived the backing board only as blocking moisture entry, oblivious to its converse ability to block moisture loss due to the “warm and dry air” he knew was deleterious. Still, it was clear advice on the multiple benefits of display enclosures and recognition that there would be aesthetic objections.

Rathgen, who had shown that low RH stopped bronze corrosion, also showed how to do it reliably in exhibits: airtight cases (metal plus glass plus care in fabrication) together with an RH sorbent (in a hidden compartment linked by fabric-covered openings). The diagram of case design in his handbook for museum curators (Rathgen, 1905) is as relevant as ever.

A few decades later, metal and glass enclosures were used routinely to control RH of panel paintings by the National Gallery of Canada (Constable, 1934; see the figure labeled “Airtight brass case for wood panel picture, National Gallery of Canada, April 16, 1934”). Ottawa has the lowest winter temperatures of any national capital; in the era before humidification, the National Gallery of Canada was likely to have had the lowest indoor RH of any national gallery (10% RH is not uncommon in unhumidified buildings in winter).

Many articles on RH-controlled enclosures, both display cases and shipping crates, emerged in the second half of the twentieth century, but quantified modeling of their behavior took three decades. Sealed shipping crates subjected to large temperature changes in transit were understood first by Toishi (1959), who showed that wooden objects could stabilize the RH in the crate. Thomson (1964) developed equations for this result, and Stollow (1966) provided a practical manual with moisture data on many materials. Unlike transit crates, the issue with RH-controlled display cases was long-term drift of RH due to case “leakage.” Thomson (1977) developed a model of RH dependence on buffer capacity and case leakage, but the big practical mystery remained: why did cases that were built of the same materials, contained the same buffer, and looked identical leak so very differently? Twenty years later, Michalski (1994a) developed equations for the four leakage mechanisms and confirmed each one experimentally. The key practical insight was that if enclosure design led to cracks at the top and bottom and if fabrication led these cracks to exceed the thickness of paper, then leakage would jump exponentially, and RH control would be lost.

As conservation science slowly came to understand enclosures and their “microclimates,” museums and galleries were abandoning them. By the mid-twentieth century, the National Gallery, London, was using the advent of new mechanical control systems to forego the glass coverings on paintings recommended 60 years earlier by Church. “Great importance has always been attached to the advantages of removing the glass from paintings, thus eliminating the irritating reflections” (Keeley and Rawlins, 1951:195). Museums opted for open display, and where cases were unavoidable for security reasons, airtightness was the least of the exhibit designer’s concerns. The last straw in regard to enclosures was the discovery by the British Museum (Oddy, 1973) that many museum case materials emitted pollutants that damaged objects. Airtightness of display cases, as in homes and buildings, was seen as a dilemma best avoided.

In the last decade, however, the tide has turned. Modern low-reflectance glass and lists of nonpolluting building materials have already dealt with the old objections. The British Museum decided most cases were not threatening their contents after all (Bradley and Thickett, 1998). Now, sustainability (and security costs) is driving a rediscovery of RH-controlled museum enclosures. In all the new guidelines (discussed later), a clause similar to the following appears: “the most sensitive material . . . will always need tight control of conditions, which might best be achieved through the use of microclimates” (National Museums Directors’ Conference, 2009).

The Emergence of Mechanical Systems and the Need for Set Points

In 1908, the Boston Museum of Fine Arts installed a central humidification and air washing system for its Huntington Building. The engineer, McCabe (1931), became the first person faced with the “big” question—what RH and temperature to aim for. He proposed an RH range for winter humidification of 55% to 60% for paintings and other works of art. Another museum engineer, Macintyre, working for the National Gallery, London, in the early 1930s, suggested the same. Neither recorded their reasoning; it could have been based on local climate or the

capacity of the unrefrigerated air washer systems of the time. Brown and Rose (1997) argue convincingly it was the system capacity. What the engineers did record was the lack of useful information on collections needs: “optimum conditions for any particular class of paintings must be more or less arbitrary” (Macintyre, 1934:16). For temperature, Macintyre (1934) suggested 60°F (~16°C) “as this is the temperature at which galleries are maintained in this country during the winter months.” I think it is safe to say that he did not intend this as a year-round suggestion since the whole discussion was understood to be about a winter problem. In summary, engineers on both sides of the Atlantic conceded that no useful information on collections needs existed, other than a qualitative call for winter humidification, so they fell back on the following logic: seasonal set points would depend on a balance of human comfort and cost and so would, of course, vary seasonally, and RH would be determined by what we now call best available technology. The logic of museum climate specifications was now fully in place and would not change until the present.

In an area for which they did have relevant knowledge McCabe and Macintyre had definite (and, in my opinion, still important) advice: “The maintenance of the plant and control gear cannot be left to the ordinary attendant” (Macintyre, 1934:16). They recognized what we would now call a risk management perspective; that is, long-term reliability matters. Proper maintenance was an important idea that, unfortunately, I have seen museums learn over and over through events that they consider unexpected but are entirely predictable. Long-term reliability was not mentioned again until Michalski (1993), and the museum community remained stuck on where to set the RH and temperature dials.

During the First World War, the British Museum stored collections in underground tunnels, and the results of damp followed by drying were disastrous: “staining, mildew and efflorescent crystals were to be seen everywhere, and many metal artifacts were in a state of serious corrosion” (Plenderleith, 1998:129). For the Second World War, they were determined to avoid such problems in underground storage: “in general, the relative humidity of the atmosphere should not be allowed to rise above 70 per cent, and authorities should aim at a relative humidity of 60 per cent combined with a temperature of 60°F” (British Museum, 1939:42). The museum numbers 60% RH and 60°F were now a decade old, but until then, they had been couched in tentative terms. I think the British Museum scientist Rawlins cast the die for what I call “magic numbers” in his 1942 article, aimed at a general museum readership: “acceptable conditions . . . are 60 °F, 60%. (Which incidentally, is easy to remember.)” (Rawlins, 1942). The main text of his article does not prepare the reader for this conclusion, rather the opposite—he noted, as had all before him, the “inability to suggest a minimum temperature at which a building should be maintained.” Not only that, his own observations of a massive collection, and presumably those of others, suggested that “many materials accustom themselves fairly well, so long as large . . . variations in RH and temperature are avoided.” So Rawlins knew that the sole evidence he had—the objects themselves rather than science—supported only the avoidance of extremes, which could have been expressed as a safe range, but he fell into the trap of a central target, “easy to remember.”

The Emergence of Stringent Specifications and Perceived Collections Needs

An American conservation scientist, Buck (1964), was the first to propose tolerable RH ranges, and he did so for different organic materials (paper, parchment, velum, fabric, bone, ivory, wood, painted wood), describing the damage to each material if the bands were exceeded. In the end, however, he assigned the same RH band to almost all of them: 45% to 65%. This is the first appearance of an acceptable bandwidth of 20% RH, and after much agony, we end up in 2014 with exactly the same number. But first, we must pass through two decades of much narrower bandwidth.

The Canadian Conservation Institute (CCI) was created in 1972 as a national advisory agency for museums, galleries, and archives. Not surprisingly, its first publication (Macleod, 1975) was an overview of the importance of RH in museums, and it reiterated Buck's range of 45% to 65% RH as tolerable. McLeod also suggested adjustments to this RH range if the building was at risk of condensation in cold winters. He proposed 35% to 55% as "an acceptable compromise." Note that Macleod's adjustment was not only about lowering the winter set point but also about lowering the summer set point; in effect, it was about maintaining the same annual RH bandwidth of 20% but lowering the average from 55% to 45%. Macleod, without actually stating it, implied that collections could be acclimatized to a new annual average.

Up to this point, there had been no mention in conservation recommendations of how to specify short-term fluctuations (hourly and daily) that were an inevitable part of mechanical control systems. Lafontaine (1979) addressed this issue in CCI Technical Bulletin 5. To my knowledge, this is the first publication containing the stringent 50% specification supported by \pm notation for daily fluctuations. This approach became the norm throughout the world within a few years. The recommended temperature set point was a range from 25°C (summer) to 20°C (for winter.) Daily fluctuations were not to exceed $\pm 1.5^\circ\text{C}$. Optimum RH was a set point between 47% and 53%, with daily fluctuation not to exceed $\pm 2\%$ (so a total range of 45% to 55%). A compromise option was a maximum summer set point of 55% and a winter set point of 38%, with daily fluctuation not to exceed $\pm 3\%$ (so a total range of 35% to 58%). This refinement did not emerge from the science of materials; it was simply the best-available-technology argument of the 1930s taken to its contemporary limits, assuming that the switching differential of thermostats and humidistats could be used to define the limits of rapid fluctuations and that a mix of human comfort and building performance would define seasonal set points.

In the first edition of the industry "bible" called *The Museum Environment*, Thomson (1978) made no explicit recommendations for climate control; instead, he summarized the available knowledge, noted what institutions were doing to control climate, and concluded with the hope that simplicity and low-energy solutions would prevail over elaborate machinery. As a practicing Buddhist, he was calling for what would later become known as sustainability. His second edition (Thomson, 1986), however, included a new appendix on specifications. I suspect that the only complaint about the first edition had been "where's the cut-and-paste

specifications for my building project?” Citing Lafontaine (1979) as support, Thomson defined two classes of control. Class I recommended RH set points of 50% or 55%, with a fluctuation of $\pm 5\%$ (no time period was specified). He accepted that other set points were possible but advised that mixed collections stay within 45% to 60% (the total class I RH range was therefore 40% to 65%, a bandwidth of 25%). The temperature recommendation was 24°C in summer and 19°C in winter, $\pm 1^\circ\text{C}$, but accepted a lower limit of 10°C. Class II recommended RH “to be kept within the danger limits 40% and 70%” and temperature “reasonably constant to stabilise RH” (Thomson, 1986:269). Although I am sure that Thomson wanted readers to take all his clarifications on class I and class II seriously, the community focused on his central target for class I: $50\% \pm 5\%$ RH.

The Pendulum Swings Back to a Broader Band

By the early 1990s, CCI began to relax its climate advice to the Canadian community at conferences and workshops on the basis of a thorough review of the relevant science and conversations with conservators, especially those with long experience observing their collections. (Relaxed recommendations applied only to fluctuations; specifications for chemically unstable materials such as those held by archives and contemporary art collections became more firmly directed at lower temperature and lower RH.) When I presented CCI’s changing advice at an international conservation conference (Michalski, 1993), the room divided into consternation over betrayal versus relief for “reality.” In a *CCI Newsletter* article titled “Relative Humidity and Temperature Guidelines: What’s Happening?” (Michalski, 1994b), I provided a table of the variable risk of fracture for various objects and various sizes of climate fluctuation and the implications were clear: although it was not CCI’s opinion that risk at ± 10 units (RH or temperature) fell to zero across a mixed collection, they considered the risk to be very small, if not zero, for most objects. Their guidelines had moved from black and white to shades of gray, with a definite opinion on which shade of gray was the point of rapidly diminishing returns.

Marion Mecklenburg had been developing similar advice for the Smithsonian. In August 1994, the Smithsonian Institution published a press release titled “Work of Smithsonian Scientists Revises Guidelines for Climate Control in Museums and Archives” in which Mecklenburg was quoted: “There can be as much as 15 percent fluctuation in relative humidity and as much as 10 degrees Celsius difference in temperature. . . . Most museums can adequately protect their collections with commercially available technology, such as the heating and cooling systems used in grocery or retail stores.” Unfortunately, this caught the U.S. conservation community by surprise (McCrary, 1994), and I think it generated skepticism of the science that has persisted to the present day (Burmester and Eibl, 2014). I remember angry U.S. conservators phoning for my reaction to the press release, and their disappointment when I said that we had been saying similar things in Canada. The Smithsonian scientists presented their reasoning at an international conference the next month (Erhardt and Mecklenburg, 1994). They summarized their arguments with a bar graph of 12 classes of material in museums, with each bar partitioned into zones of “avoid” and “caution” (as determined by their review of the literature and their own

research). No magic RH number threaded through all the safe zones. For their bar on mechanical effects, the safe zone was given as 40% to 70% RH.

In 1996, I joined the committee working on a new chapter for museums, galleries, and archives in the American Society of Heating, Refrigerating, and Air-Conditioning Engineers' (ASHRAE) handbook, the engineers' bible. We adopted the idea that mechanical risk due to fluctuations did follow shades of gray, so we created five classes of control, labeled AA, A, B, C, and D, outlined in Table 1 (unchanged in all five editions between ASHRAE, 1999 and ASHRAE, 2015). I provided each class with a short description of the estimated risks to various kinds of objects. In naming the levels, I borrowed from the psychology of bond rating nomenclature (triple A, etc.), whereby one can split small differences at the top while avoiding the embarrassing letter B. At the time, neither the science nor the marketplace justified outright rejection of the traditional stringent option that major players had struggled to meet, so we gave it the designation AA. That still left the respectable designation A for what I considered the sweet spot of $\pm 10\%$ RH (called option 2 in Table 1), offered alongside an option 1 of equivalent risk that took advantage of stress relaxation, $\pm 5\%$ RH short-term fluctuations combined with a permissible seasonal set back of 10% RH). Two other breakthroughs in the chapter, much less noticed but much more significant to energy saving, were the acceptance of a local historic average RH as an annual set point for permanent collections and very wide permissible temperature ranges. Within Canada, where CCI actively promoted its use, the ASHRAE class of control nomenclature was quickly adopted by museum consultants and conservators. In the United States and elsewhere it was also adopted by engineers but not the conservation community, except those who worked with historic houses, who were happy to see their compromises between collections and the building given formal definitions. The handbook is revised every four years. The RH and temperature sections have changed little, but the pollution sections have developed substantially.

In 2004, the Smithsonian adopted a single new specification for its more than 640 buildings on the basis of the work of its scientists (Mecklenburg et al., 2004). These specifications (Table 1) defined a year round "box" of $45\% \pm 8\%$ RH and $70^{\circ}\text{F} \pm 4^{\circ}\text{F}$ ($\sim 21^{\circ}\text{C} \pm 2^{\circ}\text{C}$), which was close to ASHRAE class AA for temperature and class A for RH. Over the next five years energy costs were reduced by 17% (Museum Conservation Institute, 2015).

Meanwhile, in Europe, the cat was put among the pigeons. Directors of large museums within the International Group of Organizers of Large-scale Exhibitions, known as the Bizot Group, began questioning the need for the stringent specifications. By early 2009, UK museum directors published National Museum Directors' Conference (NMDC) guiding principles for reducing museums' carbon footprint with a proposed interim guideline of "a stable relative humidity (RH) . . . in the range of 40–60% and a stable temperature in the range 16–25°C" (National Museum Directors' Conference, 2009). That being said, they immediately qualified this with "the most sensitive material . . . will always need tight control of conditions, which might be best achieved through the use of microclimates." Conservators from the National Archives, Tate, and University College London obtained funding for a series of expert meetings on environmental guidelines, opportunities, and risks (Bell, 2009), which concluded that

TABLE 1. Summary of current museum climate guidelines, their purpose, collateral damage, and risks due to out-of-range events. Abbreviations are as follows: AAMD, Association of Art Museum Directors; AIC, Association of Art Museum Directors; AICCM, Australian Institute for the Conservation of Cultural Materials; ASHRAE, American Society of Heating, Refrigerating, and Air-Conditioning Engineers; IPI, Image Permanence Institute; ISO, International Organization for Standardization; NMDC, National Museum Directors' Conference. © Government of Canada, Canadian Conservation Institute, 2016.

Guideline	Tolerable range ^a	Tolerable short-term fluctuation ^b	Annual set point or average	Summer set point	Winter set point
Bizot, NMDC (Velios, 2014)	40%–60% RH 15°C–25°C	±10% RH/day			
AIC, AAMD (Velios, 2014)	59°F–77°F	±5% RH/day			
AICCM (Velios, 2014)		±5% RH/day ±4°C/day			
Smithsonian 2007 ^d (Erhardt et al., 2007)	37%–53% RH ~19°C–23°C 66°F–74°F		45% RH ~21°C 70°F		
ASHRAE class AA ^e (all references to “ASHRAE” are from ASHRAE, 2015)	45%–55% RH 14°C–28°C 57°F–82°F	±5% RH ±2°C	50% RH or historic average 15°C–25°C (loan rooms 21°C/50% RH)	Up 5°C	Down 5°C
ASHRAE class A, option 1 ^e	35%–65% RH 9°C–28°C 48°F–82°F	±5% RH ±2°C		Up 5°C 10% RH	Down 10°C, 10% RH
ASHRAE class A, option 2 ^e	40%–60% RH 9°C–28°C 48°F–82°F	±10% RH ±2°C		Up 5°C	Down 10°C
ASHRAE class B ^e		±10% RH ±5 °C		Up 5°C 10% RH	Down 10°C 10% RH
ASHRAE class C	25%–75% RH Not over 30°C (86°F)				
ASHRAE class D	Below 75% RH				

Purpose of these conditions (i.e., risks that are reduced) ^c	Collateral damage to mixed collections in these conditions (i.e., risks that remain)	Risk due to RH spikes over $\pm 20\%$ but duration less than 1 hour ^c	Risk due to a sustained RH fluctuation over $\pm 20\%$, e.g., system or shipping failure ^c
<ol style="list-style-type: none"> 1. Prevent cracking, flaking, and deformation of medium- to high-vulnerability objects, e.g., paint layers on organic supports, constrained assemblies of organic materials 2. Film, photograph, document access room: reduce handling breakage due to brittleness, reduce misalignment in dimension critical playback 3. Glass, metals: reduce corrosion compared to higher RH <p>ASHRAE AA, A, B, C: As in point 1 above, but probability of damage increases with each class (not cited in ASHRAE, but risk due to any class is negligible for the next <i>X</i> years if the collection has already experienced <i>X</i> years of the conditions specified for that class, except for objects restored or acquired within <i>X</i> years)</p>	<ol style="list-style-type: none"> 1. Most twentieth-century rubber and plastic materials decay rapidly, e.g., in modern and contemporary art, industrial, and domestic collections 2. Most archival material (acidic paper, image media, electronic media) has short (unacceptable) lifetimes 3. Contaminated base metals and pyrites corrode faster than if at lower RH. 	<ol style="list-style-type: none"> 1. For thin objects with response time under 1 hour, if unenclosed, probability of cracking and flaking of high-vulnerability objects is high; medium vulnerability is medium 2. Objects thicker than 1 mm or thin objects inside moderately airtight packages and enclosures, e.g., paintings with backing boards, have small risk; if airtight enclosure, e.g., glass and backing board on paintings, no risk 3. Exposed contaminated metals if spike is to high RH: large risk 	<ol style="list-style-type: none"> 1. If unenclosed, probability of cracking and flaking of high-vulnerability objects is high; medium vulnerability is medium 2. Mold: in ~2 days if 90% RH, in ~10 days if 80% RH, in ~100 days if 70% RH 3. Exposed contaminated metals if sustained high RH: large risk of disintegration, flaking, efflorescence, maybe total loss
Prevent mold; prevent worst forms of cracking, flaking, deformation due to damp; prevent very rapid corrosion	Going over 75% RH elevates all risks of points 1, 2, and 3 above	Going over 75% RH elevates all risks of points 1, 2, and 3 above	Going over 75% RH elevates all risks of points 1, 2, and 3 above

(continued)

TABLE 1. (Continued).

Guideline	Tolerable range ^a	Tolerable short-term fluctuation ^b	Annual set point or average	Summer set point	Winter set point
IPI cool storage ^f (All “IPI” are from Adelstein 2009)	Unspecified. RH fluctuations not important if proper packaging. Temperature increases will erode lifetime (can be calculated). ISO standards provide more detailed specifications.		~12°C ~54°F	Up not allowed	Down if it saves money
IPI cold storage			~4°C ~40°F		
IPI freezing storage			~0°C ~32°F		
Dry storage metals	No formal specifications exist, but 30% RH slows down deterioration of most problematic metals enough. Salt-contaminated iron has very slow corrosion down to ~10% RH (Watkinson and Tanner, 2008).				

^a“Tolerable range” refers to the entire range of RH values permitted, including all fluctuations. It is not the range in system set points, which is an operational specification; it is a performance specification for the entire space containing collections. Also called “the box” in reference to the four-sided zone drawn on a chart of RH and temperature, such as the psychrometric chart. It is not desirable, only tolerable. All readings over the year must fit in this zone. Current guidelines do not consider that HVAC engineers’ design to a percentile, typically 1% design conditions (~4 days per year outside limits), since the naive assumption of users has been that engineers design to 0% chance of excess conditions (meaningless and/or impossible). It is important for museums that designers and operators know which parameter to favor during overload conditions, RH or temperature. In all cases it is RH first.

^bThe plus-minus symbol (e.g., $\pm X$) means that the RH or temperature can range up X and down X from a set point or an average value, a peak-to-peak range of $2X$. Some standards do not specify the exact time frame; most are per day.

a new museum climate standard should be fast-tracked through the British Standards Institute. The result was Publicly Available Specification (PAS) 198:2012, “Specification for Managing Environmental Conditions for Cultural Collections” (British Standards Institute, 2012). It broke away from picking numbers and instead advised how to think through a climate control decision.

By 2010, the U.S. conservation community started to take notice. Matthew Siegal at the Boston Museum of Fine Arts invited heads of conservation from museums and galleries all over the United States to discuss climate specifications (Hatchfield, 2011). The two conservators responsible for probably more international traveling exhibitions than anyone else—Mervin Richards (National Gallery of Art, United States) and Sarah Staniforth (National Trust, United Kingdom)—stated that they had already lived with a de facto range of 40% to 60% RH among borrowers and had not seen problems. An interim statement very similar to that of the NMDC in the United Kingdom was proposed. My memory of the meeting was heated discussion over the exact definition of short-term fluctuation limits and concern that the clause about conservators having the last word on loans would be neglected. Nevertheless, within two years, an interim guideline was

Purpose of these conditions (i.e., risks that are reduced) ^c	Collateral damage to mixed collections in these conditions (i.e., risks that remain)	Risk due to RH spikes over $\pm 20\%$ but duration less than 1 hour ^c	Risk due to a sustained RH fluctuation over $\pm 20\%$, e.g., system or shipping failure ^c
Increase lifetime of unstable materials in archives, also in museums and galleries. Lifetime ~3 times longer compared with that at 20°C/68°F		As in points 1 and 2 above; no risk if well packaged	As in points 1 and 2 above; no risk if well packaged
Lifetime ~10 times longer compared with that at 20°C/68°F	Acrylic paints, some thick plastics at risk of cracking		
Lifetime ~20 longer compared with that at 20°C/68°F			

^cVulnerability categories of low, medium, high, and very high are defined in Michalski (1996), and also described at www.cci-icc.gc.ca.

^dThe Smithsonian guideline specifies only the total box, recognizing that in practice energy considerations will usually, but not necessarily, push competent operation toward use of the lower left corner of the box in winter and the upper right corner in summer.

^eFor ASHRAE the tolerable range is derived from the seasonal set points plus short-term fluctuations, and for comparison to other guidelines, an annual average set point of 21°C/50% RH is assumed. Note that ASHRAE allows this annual set point to vary more, but it is meant to be selected once on the basis of local climate and usage reasons, not used as part of seasonal adjustment.

^fSee Adelstein (2009).

adopted by the American Institute for Conservation of Historic and Artistic Works (AIC), and it was endorsed by the Association of Art Museum Directors in May 2013 and forwarded to the International Institute for the Conservation of Artistic and Historic Works (IIC) and the International Council of Museums Committee for Conservation (ICOM-CC; Kerschner, 2013).

Specifications as of 2014: Do the Ratified Guidelines Apply Only on Loans?

In September 2014, the two major international conservation organizations, ICOM-CC and IIC, prepared a common statement on climate control guidelines that was ratified by vote at their conferences. It begins with a text about sustainability and so forth that many will treat as a preamble and proposes simply that the term “interim” be dropped from the guidelines of Bizot, NMDC, AIC, and the Australian Institute for the Conservation of Cultural Materials, all of which are individually provided in an appendix, without synthesis (Velios, 2014). This proposal leaves the reader to sort out that the different guidelines do share the same acceptable range, or box, of 40% to 60% RH and 15°C to 25°C but vary in regard to short-term fluctuations (see Table

1). The ICOM-CC and IIC statement notes that these guidelines were developed for international loan exhibitions, thereby implying that specifications for permanent collections remain up to individual users who should think through the issues raised in the main text, which are essentially a condensed version of the decision-making advice in PAS 198 (British Standards Institute, 2012). I suspect that users without technical resources will be content to say “what’s good enough for my loans is good enough for me.”

Metals, Glass, Minerals, Pyrites, Photographs, Newspaper, Tapes, Plastics, and More Do Not Agree with Human Comfort

As we have seen, museum and gallery climate specifications originated in the desire to reduce cracking and flaking of paintings due to very low RH and very high RH. Many other collections—furniture, ivories, parchment, fine art on paper—seemed to fit the same argument. No exotic machinery was needed, just upgrading of the machines that humans already wanted for their own comfort. But a second theme existed in the background—many important collections are better served by climates uncomfortable to humans. In this section I develop the three strands—awareness, specification, and science—together since they are much more closely linked than for paint and wood.

The awareness that copper and iron alloys corrode rapidly when damp must have arisen as soon as each metal was made into something usable, but the first museum specification was Rathgen’s (1905) call for very low RH cases to stop bronze disease. Passive control via airtight cases became firmly established as the responsibility of conservators or maybe the exhibit personnel but not facilities managers or their engineers. Active desiccant dehumidifiers were attached to cases in the 1970s, but it was only in the late 1990s that the responsibility for machines supporting display cases, by now used for middle RH as well as low RH, began to move from the conservators to the facilities managers. In my experience, such machines must become part of facilities maintenance if they are to survive beyond their initial conservation champions. Industry and the military have protected the interiors of large metal objects with desiccant dehumidifiers since at least the 1970s, but museums have only recently considered their application to large objects, such as the interior of airplanes (Darren Priday, Manager, Michael Beetham Conservation Centre, Royal Air Force Museum, personal communication, 2015) and the bottom half of an ocean liner (Watkinson and Tanner, 2008).

In the 1960s, glass acquired special museum RH status through the work of Brill (1975), a scientist at the Corning Museum. Glass brought a new wrinkle—two RH phenomena in conflict, one with a lower RH limit, the other with an upper limit—that remains a source of research and discussion to the present day. Koob (2012) discusses glasses that are not preserved by any RH but whose decay is certainly slowed down by an optimum RH.

Although the corrosion products of metal and glass are minerals, mineral collections as such were not given RH specifications until the systematic work of Waller (1992), who simultaneously (like Rathgen) demonstrated simple methods for reliable passive RH control of specimens. At the same time, natural history museums discovered the special RH needs of fossils

containing pyrites. Pyrite itself is better off at very low RH (Howie, 1992), but when it is present in fossils, a compromise with cracking of other components may be necessary.

By the late 1920s, it was clear that some papers and the plastic base of films were aging quickly; that is, they had poor “stability.” By the 1930s, scientists at the National Bureau of Standards (NBS) had measured the much higher relative stability of rag papers compared with wood pulp papers (Scribner, 1939). The NBS also showed the much better stability of the new acetate films compared with old nitrate film, so they recommended use of acetate films for microfilming archives (Hill and Weber, 1936). These “accelerated ageing” studies were based on the fact that higher than normal temperature speeds up chemical self-destruction, and the extrapolations were shown to correlate fairly well with natural ageing (Scribner, 1939). The obvious corollary—that low temperatures would slow down chemical self-destruction of unstable materials—did not occur to anyone for a remarkably long time.

By the mid-1950s, users noted that acetate film was also degrading (Adelstein, 1995) and by the end of the 1950s William K. Wilson and colleagues (1954) at NBS measured the decay of acetate films used as a laminating material. Not until the 1960s and 1970s did film manufacturers study the problem (Adelstein et al., 1995). Meanwhile, a second photographic stability issue arose—color dye fading. By 1970, Kodak published elegant work (Adelstein et al., 1970) quantifying the benefits of cold storage on color lifetime, using the Arrhenius method, a basic tool of chemical kinetics that would become a mainstay of conservation science, much used, much debated. In the mid-1970s, Jim Wallace, director of Smithsonian Photographic Services, became an early adopter of the cold storage strategy, probably in light of the nitrate-acetate problem (Roby, 2013). The color loss problem, however, did not seem to influence the behavior of manufacturers or archivists until 1980, when director Martin Scorsese complained loudly about it (Wilhelm and Brower, 1993:306). Henry Wilhelm, an independent researcher and industry gadfly who had advised Scorsese, eventually published a massive tome on the failings of the materials, the need for cold storage, and the means for doing so at small and large scales (Wilhelm and Brower, 1993). In 1978, J. Reilly started a university-based research laboratory that by 1985 became the Image Permanence Institute (IPI; Image Permanence Institute, 2010). Through Reilly’s proselytizing and IPI’s user-friendly tools, lifetime and cold storage finally became part of the ordinary archivist’s mindset, if not behavior.

In 1986, D. Sebera presented a graphical tool for predicting the relative lifetime of paper at any combination of temperature and RH, later made part of the online information from the U.S. Commission on Preservation and Access (Sebera, 1994). Although the data and equations behind it have subsequently been refined or hidden inside digital black boxes, I think the graphic remains influential because for the first time the preservation community could “see” that they had a continuum of options, many shades of gray, and they had to choose on the basis of the purpose of the collection, not on any clear-cut jump in deterioration.

William K. Wilson had been a junior member of the 1930s group at NBS studying paper ageing (Scribner, 1939: acknowledgement). Sixty years later, after a distinguished career carrying out or directing ageing studies, he was asked to chair the National Information Standards

Organization (NISO) committee tasked with developing specifications for libraries and archives. He could not convince the traditionalists that magic numbers from museums may not be appropriate. At the time, the preservation strategies in vogue were microfilming and mass deacidification (both soon destined to hit feasibility walls). The NISO committee was deadlocked, so Wilson published an unratified but nevertheless NISO-sponsored report on guidelines, the first of its kind for NISO (Wilson, 1995).

Magnetic tape preservation advice made a curious (wrong) detour from the path of “colder and dryer equal longer lifetime.” Researchers in the tape industry produced a graphic of lifetime curves strangely suggesting indefinite lifetime at 30% RH, regardless of temperature. In my opinion, this recommendation was a misapplication of data on two phenomena that were counterbalanced in the short term but not in the long term (Michalski, 2000: endnote 23). Their graphic led many to believe (wrongly) that tapes would survive at room temperature. The IPI, with its advice on film well established, has turned its gaze to magnetic media and plans to clarify these issues (Bigourdan et al., 2006).

The Slow and Unfinished Science of Damage and Its Application

The first museum study on cracking was instigated by “an apparent increase” in “blistering and flaking” of panel paintings in the National Gallery, London, after the “exceptionally dry weather of 1929” (Stilwell and Knight, 1934). Ten authentic panel paintings of supposed “little value” were cut into strips, some exposed to extreme RH fluctuations, some to forced bending. Most of the project focused on comparing moisture barrier coatings for the back of the panels. The attempt to create damage by RH cycles failed because it was made at 40°C to “speed up” moisture diffusion—a bad idea since that made the ground and paint more flexible. The only damage concept that emerged clearly in the conference reports is the a priori belief that only the RH response of the support matters, whether wood (Stilwell and Knight, 1934) or canvas (Macintyre, 1934), a mistake that continued until Mecklenburg (1982) corrected it 50 years later.

I think the observations that triggered the research are more valuable than the research. No gallery RH readings are available, but let’s assume that the “dry weather of 1929” was actually the winter of 1928–1929 because it was the fifth coldest in the entire century, unusual in terms of sustained cold (Weather-history, 2006). This is important because panels with exposed backs take about a week to reach three-quarters of full response (Stilwell and Knight, 1934: Test IV). February 11 to 19 was the coldest week, averaging –4.6°C (Weather-history, 2006). If the gallery was heated in winter to 15.5°C (60°F) as Macintyre (1934) states and assuming conservatively an outdoor average RH of ~80% and no gallery humidification in place, then average RH for the week would have dropped to 20%. The RH fluctuation responsible for the widely noticeable damage was not 20% or 30% but a 40% drop from the summer value of 60%.

In the early 1920s, Harley Nelson of the New Jersey Zinc Company led a group of researchers trying to understand the cracking of linseed oil house paints. In a series of papers (reviewed

in Michalski, 1991), Nelson and colleagues measured several key mechanical phenomena in a range of paints and varnishes: stress relaxation over time, moisture adsorption at various RH, and the dramatic effect of RH on elasticity and strength. In the early 1950s, F. L. Browne published a long series of articles (reviewed in Michalski, 1991) on the dimensional response of oil paints to RH as well as measuring its curing shrinkage, known later in paint research as “internal stress,” a key to understanding cracks in paint. By 1980, a great deal of relevant research had accumulated in the paint literature, but none of it seemed to enter the museum conservation field. The only “science” that permeated explanations of RH damage was the tiresome diagram of how different cuts of wood warped from the green state.

In the late 1970s, Marion Mecklenburg, a private paintings conservator frustrated with inadequate explanations of cracking in paintings, took up the study of mechanical engineering. He built his own tensile testers and began measuring tension in restrained samples as the RH changed, first samples from an old painting on canvas, then new samples of each layer in a painting: canvas, glue, and paint. In 1982, he provided a report to the Smithsonian called “Some Aspects of the Mechanical Behavior of Fabric Supported Paintings” (Mecklenburg, 1982) that laid the foundation for all subsequent modeling in the field. He established that the tension in a laminar structure is the sum of tensions from each layer; the change in tension due to an RH change depends not only on change in dimension but also on change in elasticity because the solid layers (glue, ground, paint, varnish) shrink and stiffen at low RH and expand and soften at high RH, whereas the woven layer does the opposite. When one measures the tension in restrained specimens of old paintings as RH varies from 5% to 95% and back again, as Mecklenburg did (replicated by others soon afterward), one obtains the now familiar hockey stick curve, with a valley from 50% to 75% RH, a long curved climb to maximum tension at low RH entirely due to the solid layers, and an upturn beyond about 85% RH due to canvas tightening.

A few years later, paint industry researchers Pererea and Van Eynde (1987) published what I realized was the larger model within which Mecklenburg’s ideas could fit (they were unaware of the field of museum conservation). They used the context of viscoelastic mechanics to explain “hygrothermal stresses,” including those arising from curing shrinkage, and provided the correct integral equation.

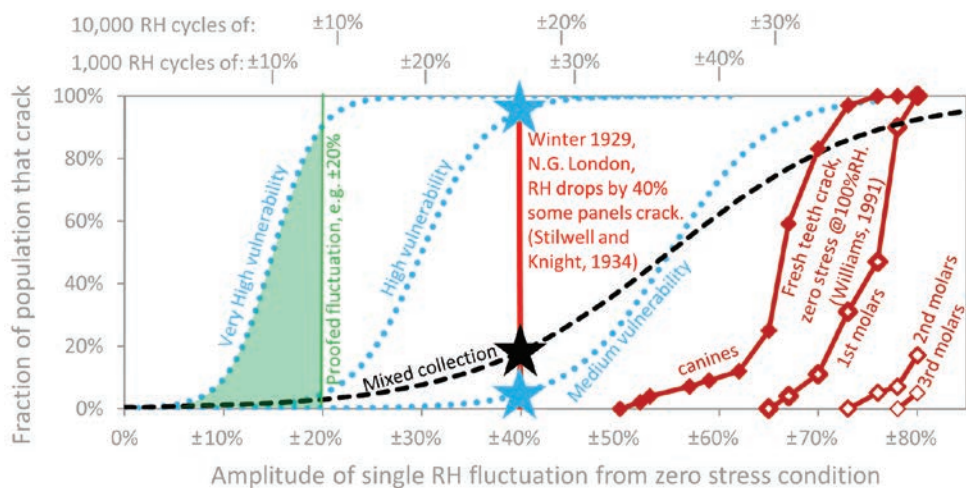
By the time of the 1991 Art in Transit conference (Mecklenburg, 1991), museum conservatorship had advanced considerably. Mecklenburg and his Smithsonian colleagues presented computer modeling that generated the same patterns of cracks one often sees in paintings on canvas, some by drops in RH, others by drops in temperature. After modeling preexisting flaws in panel paintings, their final advice was cautious: “All panel paintings should be maintained in a very narrow relative humidity environment” (Mecklenburg and Tumosa, 1994:190). I presented a critical review of the copious “unknown” literature that supported and extended Mecklenburg’s data and placed it all within a viscoelastic framework (Michalski, 1991). (Just before all the stacks in the Canadian central government research library were closed to users, I had skimmed the table of contents of every volume of every journal in the paint, glue, and

textile industries back to 1900). Since the conference was on vibration in transit, I had also begun to develop a fatigue mechanics approach that I later applied to multiple fluctuations (Michalski, 2014) because the following question always came up: What about thousands of small fluctuations?

Three years later, Mecklenburg and his colleagues were no longer concluding with “a very narrow relative humidity environment” but rather the opposite (Smithsonian Institution, 1994; Erhardt and Mecklenburg, 1994). No change in the science had occurred, but the presumed question had been changed from “What is tolerable under a worst-case scenario for a panel painting?” to “What is tolerable for a typical object in the group known to be vulnerable?” This latter question has guided all of Mecklenburg and colleagues’ articles on specifications to the present (all key publications up to 2007 are online in the Smithsonian Library’s DSpace Repository at <https://repository.si.edu>, under Museum Conservation Institute). Mecklenburg’s approach to the question is as follows: Assume that the “yield point” of materials is the criterion for unacceptable damage, that is, the amount it can stretch and still rebound completely. Assume that the most representative geometry for vulnerable objects in the whole collection is uniform constraint of the vulnerable component, e.g., a uniform paint layer held uniformly by some other stronger component, and assume that this component is at zero stress at the climate set point. (In my own advice, I refer to such assemblies as “medium vulnerability.”) Now calculate the fluctuation that will cause the strain that reaches the yield strain, taking into account the nonlinear relation of shrinkage to RH for materials such as wood. Having done this for various materials, he and his colleagues conclude that 30% to 60% RH is safe “for general collections” but then state “There are exceptions...severely degraded materials, objects with weak or degraded adhesives (especially veneers and inlays), or objects such as drums and Japanese screens with pre-existing stresses should be kept in more stable environments.” They suggest enclosures for such objects. Their final recommended range for building control is 37% to 53% RH but which exceptions this “conservative” range does or does not cover is left unclear (Erhardt, 2007). This category of “exceptions” is precisely what concerns conservators.

My own work on the science since 1994 has also built on Mecklenburg’s (1982) foundations, adding real-world flaws, fuzziness, and fatigue (Michalski, 2013), and someday I would like to be able to predict the curves of Figure 1, but until then my approach to specifications and tolerable fluctuations has changed little since I surveyed what was known 20 years ago (Michalski, 1991, 1993, 1994b) and introduced the idea of proofed fluctuation (Michalski, 1993). I will address this in the next section.

Fortunately, new researchers have entered the field, most notably the group in Cracow under the leadership of Roman Kozłowski. A key contribution was their measurement of fatigue cracking in samples of gesso on poplar subjected to thousands of mechanical cycles applied to the wood to simulate its expansion and contraction by RH fluctuations. By computer modeling the maximum plausible frequency of cycling of a panel by RH, they concluded that gesso on wood could tolerate $\pm 15\%$ RH fluctuations for at least a century (Rachwał et al., 2012).



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FIGURE 1. Cumulative population distributions of vulnerability to RH fluctuations. Red solid lines show data for fresh mammalian teeth, which represent ivory and behave like wood in terms of having different responses across the grain; canines have solid cores and hence are more vulnerable to splitting than molars, which are hollow (Williams 1991). Dotted lines represent three vulnerability classes (very high, high, medium), each one double the vulnerability of the next, defined in Michalski (1996). The dashed black line shows the vulnerability of a mixed collection, which can contain all vulnerability classes, including some objects with no vulnerability. Upper scales show equivalent RH fluctuations due to fatigue at 1,000 cycles (e.g., a millennium of seasonal lows) and at 10,000 cycles (e.g., 30 years of daily cycles to objects thin enough to respond), based on Michalski (2014). The bright green vertical line at $\pm 20\%$ RH represents various proofed fluctuations: either one cycle of $\pm 20\%$ RH or 1,000 cycles of $\pm 13\%$ RH or 10,000 cycles of $\pm 9\%$ RH; it truncates all distributions precisely, such as most of the high vulnerability objects (green zone). The vertical red line near the center represents flaking of panel paintings in the National Gallery (N.G.) London in 1929 due to a 40% RH drop (estimated in the section on the science of damage). If almost 100% of the collection flaked, it would mean it was a high vulnerability collection (top star). If less than 20% of the panels flaked, it implies that they were a medium vulnerability collection or even a mixed collection (lowest two stars). The role of heritage science is to collect data and build models for these plots and to confirm them through observations of actual collections and to do the same for mechanical risks from temperature fluctuations.

What is Stable? What is Safe? What is Tolerable? The Five Errors

Throughout the decades of pontification on climate specifications, the one thing everyone seemed to agree on was the absolute goodness of a “stable” climate. “Stable is safe” has become the rallying cry of the new traditionalists (Burmester and Eibl, 2014). We have seen the obvious exceptions: metals, glass, and minerals; their issue is staying within sharp RH boundaries, not fluctuations. Even archive advisers used to be adamant about stability for chemical and mechanical reasons until very recently, but the old bugaboo that fluctuations speed up chemical self-destruction above and beyond simple addition of each moment’s effect has been laid to rest by IPI (Bigourdan and Reilly, 2003). Furthermore, paper conservators are beginning to accept (correctly, I believe) that unrestrained expansion and contraction of paper sheets is not a danger; the National Archives (2013) just finished a test of a repository previously stable at 45% RH that is now allowed to float up in summer (50%) but down even lower in winter (30%), thereby saving not only energy but collection lifetime. For archive records that are mechanically

vulnerable to fluctuations, advisers are beginning to integrate package performance with flexibility in system operation (Bigourdan, 2012), opening the door to off-peak utility use, etc.

What, then, about the vulnerable stuff? I think there have been five errors in argumentation on all sides.

Error 1: Assuming Stability Means Just Most of the Time

For human comfort and preservation of chemically unstable materials, being within specification 99% of the time is good enough, great even. For mechanical damage, it is not: 3 days per year, or 30 days per decade, outside specifications is all that matters in the end. In risk analysis, hazards such as fluctuations vary over a continuum from frequent-trivial to rare-catastrophic, e.g., earthquakes, car collisions, etc. The largest contributions to total risk, the best events to try and reduce, are usually from the middle to high end of the range—the not so rare but still serious events. Table 2 examines the risk from two types of fluctuation events: the frequent ones we obsess about and the occasional failures we do not discuss. It is not necessary to be precise about what “tiny” or “large” damage means (although I believe these terms are technically defensible). The point of Table 2 is just the logic of long-term preservation: less frequent but larger fluctuations are the biggest risk to museum collections unless, of course, the object is inside an enclosure. Even if there is a tiny increase in risk by having $\pm 10\%$ RH compared with $\pm 5\%$ RH, it does not actually matter to total risk because that is dominated by the one bad event.

Error 2: Unverified (Unbelievable?) Claims of Control

Jonathan Ashley-Smith first raised the following concern in the United Kingdom, and Matthew Siegal has reiterated it in the United States: many museums, even those with well-intentioned systems, do not stay within $\pm 5\%$ RH. Even $\pm 10\%$ might be exceeded once in a while. Rather than the hypocrisy issue raised by others, I am concerned with the two arguments based on

TABLE 2. Risk from a mix of routine RH fluctuations plus a rare failure event in 30 years, for an object of very high vulnerability, i.e., never exposed beyond $\pm 5\%$ RH before today.

Conditions	Damage due to the routine fluctuations		Damage due to a failure event of 30% RH fluctuation		Total risk per 30 years
Control to $\pm 5\%$ RH, except one failure event in 30 years	None	+	Large; Small if fluctuation shorter than response time	=	Large; Small if fluctuation shorter than response time
As above, object enclosed.	None	+	None	=	None
Control to $\pm 10\%$ RH, except one failure event in 30 years	Tiny None if $m \gg n$	+	Large; Small if fluctuation shorter than response time	=	Large; Small if fluctuation shorter than response time
As above, object enclosed.	None	+	None	=	None

these claims: (1) the feasibility of tight specifications for everyone and (2) the precautionary counterfactual scenario (i.e., my collection is undamaged, and I have never gone beyond $\pm 5\%$ RH; therefore, I have no proof that conditions are safe beyond $\pm 5\%$ RH, and damage becomes a possibility, so precaution tells me to never go there). This argument is legitimate, but its truth rests in the truth of the $\pm 5\%$ control, that is, how long “never” was. I think it is common that good systems maintain $\pm 5\%$ RH in one location for weeks, longer if the weather is benign, but in a nineteenth-century building with crowds and limited ductwork, I doubt that each object stays within $\pm 5\%$ RH through all seasons, and I know that control has not lasted decades. Overloads happen. Heating-cooling changeover gets erratic. Systems get repaired and replaced (never mind accuracy, which makes anyone who has done rigorous RH measurement sigh). Until galleries claiming such control share seamless and verifiable climate data, not only does their argument ring hollow, but the community loses its best chance to understand the vulnerability of collections because I do believe their observation of no damage.

Error 3: Ignoring the Reality of Proofed Fluctuation

A history of deviations from perfection, as noted in error 1, can be seen as bad news, but there is good news too. Whatever the worst fluctuation that a collection has experienced, anything less will cause very little risk, unless the collection has aged chemically (decades for old paint). Michalski (2014) provides a method for extrapolating to multiple future cycles from a single worst historic fluctuation of $\pm X\%$ RH; for example, at $\pm 0.9X\%$ up to 30 future fluctuations are tolerable, at $\pm 0.65X\%$ up to 1,000 future fluctuations are tolerable, etc.

Error 4: Ignoring the Fact That the Value at Risk Does Not Reside in Original Old Material

Old things have certainly seen at least $\pm 20\%$ RH fluctuations in their time and often more. If old furniture and paintings appear flawless today, it is only because of restorations. Any original seams or layers vulnerable to $\pm 20\%$ RH popped long ago. If an old object is actually vulnerable to fluctuations smaller than $\pm 20\%$ RH, it is primarily the reglued seams and painted infills that fall apart, not original material. I am not advocating the popping of good (and expensive) restorations and the collateral damage that comes with repetitive restoration; I am only asking that we stop pretending that it is nonnegotiable original material that is at risk in the range being debated because it is primarily restorations that are at risk. Thus, an additional reason that the risk from unusual fluctuations in Table 2 is much larger than that of frequent small fluctuations is the greater value of the material involved. Original material is at risk to small fluctuations only in new objects, and such collections do warrant separate decision making.

Error 5: Answering a Different Question from the One Asked

A good politician listens politely to the interviewer's question and then answers a different question, for which he has a very good answer. Who had the “right” question depends on your perspective. I think conservators looking for climate advice intended the following

question: What is the maximum fluctuation tolerable by any and all objects in my collection? In other words, what rule covers the exceptions as well as the typical objects. I think scientists annoyed at conservators not listening to their “rational guidelines” (Erhardt, 2007) had given a good answer to a different (and simpler) question: What is the fluctuation that science predicts will be tolerable by typical objects within each of the groups known to be vulnerable? I think the proper question to science, illustrated in Figure 1, will answer both these questions: What is the distribution curve for critical fluctuations across the various objects in a collection (from which we can then derive averages and exceptions)? When we can answer that question, we will have a tool that we can bring to the table alongside curatorial and technical expertise to answer the real question: What is the best sustainable climate we can provide for our collections?

Conclusions

Creating climate specifications for collections is like buying a suit: a one-size-fits-all outfit is very precise but looks awful on almost everyone, an off-the-rack suit in one’s own size is pretty good and works for most of us, but a tailored suit looks best, usually lasts longer, and costs less in the long run. However, the initial costs and time required are high, and there will always be naysayers who cannot see the difference.

What advice would I give to the management of a large museum looking for a set of climate control specifications? Read and act on the decision-making approach of PAS 198 (British Standards Institute, 2012). During negotiations, please avoid errors 1 to 5 in the previous section. That said, the process is unclear and daunting, so here are my action recipes for three levels of increasing opportunities for sustainable design but increasing effort:

1. For one size fits all, use Smithsonian or AIC, IIC, ICOM-CC, and Bizot specifications and adjust where necessary considering the commentary in Table 1.
2. For off the rack, look at the museum chapter in ASHRAE (2015) and *IPI Media Storage: Quick Reference* (Adelstein, 2009). Conservators select preferred targets, engineers and architects indicate cost options, and they negotiate.
3. For a custom fit, use the following recipe: (a) Curators analyze the implications of the institution’s mandate for preservation criteria of each collection. (b) Conservators analyze the vulnerabilities of the collections to various climates. (c) Engineers and architects analyze the implementation options for various climates in terms of life cycle costs and energy. Then everyone sits together and negotiates an optimum for the institution. It is probably wise to iterate this process a few times, that is, first build shared awareness, then identify areas of overlap, then refine.

Finally, let’s recognize that the only realistic method for long-term RH stability is an airtight enclosure, whether an object is on display or in transit or in storage. If one truly believes that an object must never exceed a certain range in RH, it is irrational to expect mechanical systems to be that perfect. Once in place, enclosures open the door to many savings in design and operation of that mechanical system.

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PRESENTATION

Risk Assessment and Assignment of Environment Parameters

R. ROBERT WALLER

ABSTRACT. Despite many decades of experience concerning ourselves with environmental parameters for the protection of cultural property as outlined by Michalski (this volume), huge gaps in our knowledge as well as uncertainties of many kinds remain. It is in exactly these situations of scant firm knowledge and high uncertainty that a risk analysis approach is most beneficial. The purpose of this paper is not to exhaustively describe how a risk analysis approach deals with reducing knowledge gaps and other forms of uncertainty. Instead, the emphasis here is on developing a clear understanding of what a risk is, how it is defined, and how various parts of an institution are able to contribute, according to their particular perspective, to collection-environment risk analysis. This information will lead to enhanced understanding of environmental parameter specifications and a more effective and cost-effective definition and application of those standards.

Introduction

The programmatic activities of any museum, including the simple holding of collections over time, will inevitably expose its collections to risks of deterioration, damage, and loss. Exposure to risk can occur when collections are on exhibition or on loan, in transit, in storage, or while they are being handled, treated, or studied. The underlying principles of collection management—of striking a balance between the dual goals of preservation and accessibility—is a form of risk management that ensures informed decision making with input from all of the critical stakeholders responsible for protecting collections against damage, loss, and exposure to harmful environmental conditions. Risk assessment is therefore a principal component of sound collection stewardship. It should be approached in an informed, deliberate, and scientific manner.

Demonstrating the dangers to collections posed by an inappropriate environment, even when that environment is the often-quoted 70°F/50% RH “standard specification,” tachyhydrite, a rare mineral, will dissolve within several hours when exposed to conditions of 70°F/50% RH for just a few hours. A time-lapse video of this process was produced by the Canadian Museum of Nature (2016). Although this particular video was staged, it does demonstrate the extreme vulnerability of some parts of museum collections. For any specified environmental condition (temperature, relative humidity, pollutant, and light level) examples can be found of collection items that will not just be unstable, but will deteriorate or be damaged very rapidly. Therefore, it is helpful for us to give up hope of any single, simple set of environmental specifications that will be universally applicable to collections. It is essential for us to consider variations in the sensibilities of collection items, as well as issues of maintaining specified conditions both over time and throughout collection spaces.

The term *risk* is familiar to everybody and is increasingly used in connection with collection care and management. By now, a variety of collection risk assessment approaches and methods exists. Most are designed for a particular purpose or to emphasize a particular perspective and work best when applied to similar situations. Examples include the following:

- The approach of English Heritage combines collection risk, condition, and significance audits, yielding a combined measure of the scale of conservation issues as well as recommendations for broad priorities (Xavier-Rowe and Fry, 2010).
- The Canadian Conservation Institute uses ABC scales that prioritize recommendations for reducing risks in conservation reports and, through International Centre for the Study of the Preservation and Restoration of Cultural Property (ICCROM) courses, has suggested the broader application of these simple scales (ICCROM, 2007).

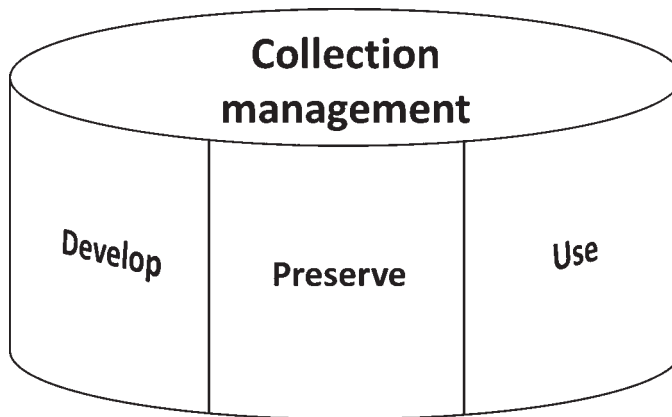


FIGURE 1. Preservation must be seen as a subsystem of a broader collection management system.

- Heritage Preservation provides a guide to identifying potential disasters and reducing their effects; it is designed mainly to connect collection care staff to the emergency preparedness and management field (Heritage Preservation, 2013).
- The University of California Berkeley Library is developing an approach for placing library collection risks within an overall University of California, Berkeley, enterprise risk management system (Ogden, 2012).
- The Cultural Property Risk Analysis Method (CPRAM) of the Canadian Museum of Nature embeds risk awareness and competence throughout collection-holding institutions (Waller, 2003). It is most suited for application to medium to large institutions.

Although this paper is at a general level that is broadly applicable to any risk analysis process, the following discussion draws largely on the CPRAM model as the most fully developed and described model.

An underlying principle of risk assessment is the necessity of a system-based approach. In the case of collection risk assessment, the preservation system must mesh with other collection and institutional systems if it is to be effective. Consequently, CPRAM is based on a systems understanding of collection management that comprises three subsystems (see Figure 1). These are development (collection planning, acquisition, curatorship), preservation (preventive care, conservation treatment, object storage and housing), and use (research, education, exhibitions). In application, risk assessment must embrace uncertainty in four dimensions: model structure, variability, ignorance, and randomness.

Model Structure

The first source of uncertainty, model structure, tends to be the largest. At the most fundamental level, an implicit assumption in model structures is that the future will resemble the past and that the past can serve as a guide to the future. This assumption arises naturally because all of our empirical evidence comes from the past. But it is important to bear in mind that it is an

assumption, and the future may in some respects diverge substantially from expectations based on past experience.

The most important aspect of a risk model is a goal. Risk models are based on a clear long-term operational goal and define risk as a deviation from that goal. For example, consider a hypothetical collection of 25 objects: five ceramics, five prints, five textiles, five natural history specimens, and five works of art. The goal for this collection is defined as moving it forward undamaged and intact 100 years into the future. Of course, reality usually has other plans: some objects will fade or deteriorate, some objects will be damaged, and some may be lost on account of various agents of deterioration and types of risk. There will also be small chances of a catastrophic event that will affect the entire collection. These departures from the goal of preserving the collections for a specific time period in the future are the risks we seek to identify, understand, and reduce.

The definition of what is known as a “specific risk” (Waller, 2003) can be broken down into three parts: sources, paths, and effects of departures from a defined goal. For purposes of illustration, I will apply these concepts to RH in this paper, but the concepts apply to any type of environmental hazard. In the case of RH, one can think of the three elements of risk as follows:

SOURCE. What is the original cause or problem that could lead to departure from the goal? For example, it could be a set point that is not achieved, a temperature gradient, or an HVAC failure.

PATH. What parts of the collection are fully exposed to the source RH and thus potentially at risk? How are they, or can they be, protected? For example, some vulnerable objects could be given additional protection to mitigate risk through storage within cabinets and/or containers. Those containers serve as blocks to the path aspect of the risk.

EFFECT. What kind of damage (i.e., mold, hydrolysis, corrosion, or fracture) is done to the collection as a result of departures from the goal?

In general, understanding the source of risk is often routed within the domain of facilities management. Understanding the path to damage is largely within the domain of collection care. Finally, understanding the material effect of a risk is within the domain of conservation science (although interpretation of the value impact of those effects must be based on collection user judgments elicited by collection care professionals). How do the three domains work together in risk assessment and management to collaboratively safeguard collections?

Facilities management staff are responsible for seeing that set points are achieved, that temperature gradients are controlled, that buildings and collection hardware combine to minimize the effect of HVAC systems failure on collections, and that building-level plans are in place for when HVAC systems fail. Collection care personnel are responsible for knowing which collections are sensitive or vulnerable to variations in temperature and humidity and for mitigating exposure to those conditions, for example, by housing collection items in storage cabinets, containers, or other protective microenvironments. Conservation scientists are responsible for understanding and quantifying the effects (damage) RH may have on vulnerable collections.

Variability, Ignorance, and Randomness

Embracing uncertainty also means coming to terms with the variability, ignorance, and randomness of risk and capturing these within the risk model. Again, it is helpful to think in terms of sources, paths, and effects and of the three professional, discipline-specific domains associated with them.

Facilities Management

Facilities management, in collaboration with collection care teams, can conduct periodic intensive environmental audits to characterize RH variability through time and space (Ntanos and VanSnick, 2010; the “investigative” monitoring suggested by Brown and Rose, 1997). Collection care must continue to provide verification monitoring (the “confirmatory” monitoring suggested by Brown and Rose, 1997) to avoid problems known as common mode failure, where a single technical problem can compromise both the controls for and operation of an HVAC system. In such cases, like flying through clouds without instruments, all sense of the real situation can be lost. Facilities management, notwithstanding the sophistication of modern building management systems, might perceive this collection care environmental monitoring as a potential guardian angel in watching for this rare but potentially disastrous common mode failure.

Facilities management should also characterize the expected frequency and severity of environmental excursions expected over long-term system operations over several decades from, for example, (1) cases of load exceeding capacity because of a run of unusually damp days, (2) control system interruptions that cause spikes in RH, (3) multiple-day power interruptions at regional or national levels, and (4) failure rates during HVAC system wear-in and wear-out phases as well as the midlife phase. In risk assessment, thinking about such expected departures from specifications over decades-long periods is at least as important as looking at short-term data.

Collection Care

Collection care identifies the most sensitive objects and the overall distribution of sensitivity across objects. For example, within a collection of panel paintings, you have a range of sensitivities from paintings on wood, which are among the most vulnerable of collection objects, to paintings on honeycomb aluminum substrates, which are highly stable. Likewise, after two hours of exposure to high RH, most pyrite crystals remain stable, but some do not. In a collection in which some parts are more vulnerable, highly sensitive items may need special protection at the object level or case level. In those situations a limited budget for environmental controls might be better invested in hardware and/or packaging and buffering materials than in building- or room-level mechanical systems. Of course, the distribution of vulnerability varies between kinds of collections; in some, practically all objects will be similarly vulnerable. Enhancing our ability to characterize and communicate variable environmental sensitivities across various kinds of collections is a major current challenge for the collection care profession.

Collection care also needs to characterize procedural controls on environmental exposures at the collection and object levels. Problems at these levels can thwart the best efforts of facilities

management. For example, if a collection item is wetted during cleaning, it may take many weeks to completely dry. Placing that item in a well-sealed cabinet can raise the RH level within the cabinet to near 100% RH for many weeks. Similarly, placing cabinets against a cold wall or in an area subject to water leaks may cause extreme high relative humidity levels that no facility-wide mechanical system can control.

Conservation Science

A key role for conservation science is characterization of damage functions for representative sensitive materials, structures, and objects. Fortunately, we can draw on a rapidly growing pool of information provided by, for example, Mecklenburg (2007a, 2007b), Lankester and Thickett (2013), Strlic et al. (2013), and Thickett et al. (2013).

Conservation scientists also can take the lead in working with collection care personnel, facilities management staff, and risk analysts to bring all these analyses together to create an overall risk model. In doing so, adopting a comprehensive model that facilitates shared understanding (Waller, 2008) will be important.

A comprehensive risk model that will allow rational risk-risk and risk-cost trade-offs will do the following:

- comprehensively consider all sources of deviations in RH (and other environmental factors) and express them as distributions reflecting frequency of occurrence coupled with anticipated severity measured as extent and duration of deviations
- consider what parts of a collection are susceptible to these deviations and the damage functions in the case of a deviation, adjusting for distributed collection-level controls (such as objects receiving special protective measures, storage, or housing)
- pull together expertise from across the fields of facilities, collections, and conservation science

Conclusion

The three key elements for defining a specific, quantifiable risk from a hazard-damage concept are the source of the hazard, the path taken by the hazardous agent from the source to collection, and the effect of the agent on collection items in material change and in loss of utility value. Each of these three elements is primarily associated with one of three major collection stewardship functions: facilities management, collection care, and conservation science, respectively. These professions must work together to characterize, identify, and manage risks.

Effective risk management requires establishing a systematic process for characterizing risks and developing strategies to address them. Because we work with scarce and incomplete knowledge, risk assessment can never be foolproof, but it will improve over time as more data are gathered and our understanding both broadens and deepens.

Risk managers need to do the best they can with any given state of knowledge and be open to adjustments as new knowledge becomes available. They need to establish a process for developing specifications that is inclusive of all relevant subject matter experts; otherwise, risks will

be missed or misunderstood. They should also systematically document everything they do; if not, lessons learned this week will be forgotten by next week.

Risk assessment is not easy, but it can be easier than you might fear provided you follow a clear path.

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PRESENTATION

Conservation Environments, Museum Buildings, and Sustainability

MICHAEL HENRY

ABSTRACT. This paper explains the chapter in the American Society of Heating, Refrigerating, and Air-Conditioning Engineers' handbook pertaining to museums to nonengineers, especially collection managers and conservators. This paper focuses on the relationship between collections environmental control and envelopes, that is, the structures that protect interior environments from external conditions, specifically from the damaging forces of thermal energy and moisture.

Introduction

James M. Reilly, director of the Image Permanence Institute, likes to say that “geography is preservation destiny.” The external climate drives changes in the environment within a building that can affect collections, and climate is determined in large part by geography.

From a building engineering perspective, there are 17 climate zones in the United States and its territories, defined by their characteristic long-term regional statistics for temperature, moisture vapor, precipitation, and other climatic factors. Moisture zones vary from east to west and are designated by letters: A, moist; B, dry, and C, marine. Thermal zones vary from south to north and are designated by numbers from 1, hot, to 8, subarctic. Some examples are as follows:

- Washington, D.C., is in zone 4A: mixed/humid. Heating loads are greater than cooling loads. To keep interior environments safe for most collections, structures in this zone need dehumidification throughout much of the year, especially in summer, as well as humidification during the winter.
- Boston is in zone 6A: cold/humid. It has a colder and drier climate than Washington, D.C. Collections structures in this zone do not need as much cooling as in Washington but still require dehumidification in the summer as well as humidification during winter and the colder months in spring and fall.
- Phoenix is in zone 2B: hot/dry. The climate in this zone is mainly dry, but there is an annual spike in moisture during the summer, which creates the need for some dehumidification of collections spaces in addition to humidification during the remaining months.
- Miami is in zone 1A: very hot/humid. The need for dehumidification of collections structures in this zone is year-round, even during the winter months when there may be a small heating load.

Expected Climate Changes

Global climate change adds new complications because it means the frequency and severity of climate events may differ in the future from what we have come to expect from the past. For example, we generally use historical temperature and moisture data to size an HVAC system with a 20–35 year life span or to design a building envelope meant to last 50–100 years or more, as in the case of monumental buildings such as those at the Smithsonian Institution. But climate change means the future may, relative to our historical data, hold the prospect of increased duration and frequency of extreme conditions, increased thermal and moisture loads, greater risk of flooding, and other associated changes. Climate change projections for the northeast United

States, for instance, suggest that over the next several decades, we may see substantial increases in average temperatures; shorter winters with fewer cold days and more precipitation; more extremely hot days; longer, hotter summers; and sea level rise.

These changes have implications for structures that house collections, such as longer periods of heavy cooling loads, greater risk of power interruptions, increased dehumidification needs (but possibly less need for humidification in winter), and more storms, with associated increases in moisture load and collateral effects.

The Building Envelope

The building envelope is a collection's first line of defense against the exterior climate. It maintains the desired interior environment, provides some protection when systems fail, and, when properly designed, can reduce the thermal and moisture loads and the need for, and expense of, temperature and relative humidity management by the HVAC system. The envelope consists of any portion of the structure exposed to the exterior climate, both above and below grade, such as roofs, walls, floors, doors, windows, eaves, gables, and so on. Exterior thermal and moisture effects mediated by the building envelope include the following:

- thermal gains from solar radiation and thermal losses from reradiation at night
- absorbed water from rain
- water vapor from drying of absorbed water
- thermal losses and gains due to conduction with soil or outside air
- thermal and water vapor losses and gains from infiltration of air through the envelope
- moisture gains in both the liquid and vapor state from soil moisture

Use of a building adds thermal and moisture loads within the envelope such as thermal gains from lights and equipment, thermal and water vapor gains from occupants, and thermal and moisture gains from building systems. Another consequence of occupation is the need for exterior air for ventilation, with the associated thermal and moisture loads to bring the air to the desired interior temperature and relative humidity.

The thermal and moisture performance of the building envelope sets the basic parameters for what can be achieved in the internal environment. Common sources of guidance for collections environment building envelopes include jurisdictional codes (building, fire, systems, and energy conservation codes) and chapter 23 of *ASHRAE Handbook: Heating, Ventilating and Air-Conditioning: Applications* (American Society of Heating, Refrigerating, and Air-Conditioning Engineers [ASHRAE], 2011). Additional guidance for historic and monumental buildings is provided in Association for Preservation Technology and American Institute for the Conservation (1992), National Park Service (1995), and American Institute for the Conservation of Art and Historic Artifacts (2014).

Chapter 23 of the ASHRAE Handbook

Chapter 23 of the ASHRAE handbook is the definitive source for information on building envelopes and collections environments, although this may not be widely known in the community

of building engineers and architects, where museum work is not a day-to-day activity. It provides information and guidance but not implementation methodology, which must be worked out in each case by the architects, engineers, and collections personnel of each project or building on the basis of the specifics of the climate, building envelope, HVAC system, and the environmental vulnerabilities of the collection.

This chapter breaks down building envelopes into several classes based on construction characteristics and occupancy considerations that determine the thermal and moisture performance of the envelope. It then identifies the corresponding realistically achievable environmental control. The following three classes are examples:

- Class IV: Heavy masonry, composite walls, storm windows. Performance characteristics include low to moderate air and moisture exchange, high thermal mass, moderate moisture buffering mass, and solar radiant gain at windows.
- Class V: Insulated, vapor retardant, double glazed, with vestibules. Materials are thin and light compared to those in class IV. Performance characteristics include low air and moisture exchange rates, low to moderate thermal mass, low moisture buffering mass, and solar radiant gain on dark surfaces.
- Class VI: Tight construction, perimeter buffer, limited occupancy. Performance characteristics include low air and moisture exchange rates, low to moderate thermal mass, low moisture buffering mass, and interior spaces buffered from exterior surfaces by cavities or corridors. Purpose-built museum storage facilities might fall into this class.

Some specialized envelopes used for collections are not covered by chapter 23 of the ASHRAE handbook. These include subgrade structures and vaults, which tend to be thermally stable, and greenhouse-like glass structures, like some modern museums, which have high solar gain and tend to be thermally unstable.

Chapter 23 of the ASHRAE handbook defines five different classes (AA–D) of environmental control for museums, galleries, libraries, and archives, each class presenting a different set of risks and benefits to collections. Most purpose-built museums perform in classes A or B, with some in AA. In practice, temperature control is typically very tight (AA), but moisture control may be closer to B ($\pm 10\%$) because it is easier to control temperature fluctuations than relative humidity variations.

Nonmechanical Strategies for Improving Envelope Performance

A widespread tendency is to focus on the mechanical systems for environmental control. However, interior environments can also benefit from “passive” strategies that focus on building envelope performance.

Although the term *passive* is common in this context, *nonmechanical* is perhaps more accurate since the strategies in question require commissioning and maintenance, just like mechanical systems. These nonmechanical strategies can help to reduce thermal and moisture loads on the interior environment, moderate fluctuations, and thereby allow a building system to operate near peak efficiency more often. The employment of nonmechanical envelope strategies can

also reduce the required size and capacity of mechanical systems. Some essential nonmechanical strategies include the following:

- incorporating vapor retarders in the envelope
- controlling moisture at the source with roof and subgrade drainage and other strategies to keep surface and subsurface water away from the building
- minimizing uncontrolled air and moisture exchange at windows, doors, flues, and envelope perforations
- minimizing or controlling direct and indirect solar gain with strategies such as landscaping for shade, shades/blinds/filters on windows and skylights, and cool roofs
- zoning interiors according to environmental needs, with more stable needs in inner spaces, and less stable needs along perimeters and under roofs
- separating collections zones from people zones and recognizing that the thermal comfort expectations of visitors will differ from museum staff because of differences in clothing as well as duration of stay and level of activity
- managing peak visitor counts, especially on peak cooling days

Thermal mass is an important nonmechanical strategy for achieving stability in interior environments. It affects the exchange of thermal energy between interior and exterior and can buffer swings in relative humidity as well. However, there are limits on what can be done with thermal mass; the volume-to-mass ratio must be right to realize the benefits, and this balance is difficult to achieve with large, voluminous buildings.¹ Some new building materials—both phase-change materials and moisture-absorbing materials—hold out the prospect of effective moisture buffering as well as thermal stability with less mass.

Multiple envelopes (“box-in-box” enclosures, such as an inner collections storage area surrounded by perimeter corridors) are an effective way of controlling interior environmental zones. Cascading envelopes make inner spaces more stable because such spaces are removed from direct exposure to the exterior environment.

Data and Simulations

Envelope damage and the resulting hazards to collections can arise from the interaction of liquid water, water vapor, temperature, materials, and other factors in various, extremely complex ways. Understanding these risks requires a dynamic simulation of heat and moisture effects, such as the WUFI (German acronym for transient heat and moisture transport) computer model (<http://www.wufi-pro.com>). But a note of caution is required: although a program like WUFI can be very useful, even the most sophisticated simulations should be applied with awareness that the assumptions on which the model is based may be idealized and not represent real-world variations in envelope construction.

More generally, monitoring temperature and relative humidity provides valuable data on the conditions surrounding collections. But again, it is important to think about what these data mean and how they might be misleading. Do not simply print out data logger charts and look at

the trend line; analyze the data, parse them by season, and look at ranges and fluctuations with respect to both long- and short-term time frames.

Building Systems

Finally, although most of this paper has focused on envelopes rather than building systems, a few closing words on systems are in order:

- Keep it simple and comprehensible.
- Make them resilient.
- Separate dehumidification from cooling.
- Minimize outside air; if you need a lot, precondition it, especially for moisture reduction.
- Prioritize RH control over temperature control.
- Provide ample space for service and repair.
- Commission the system.
- More is not always better.

Note

1. Structures that are below grade or bermed effectively have infinite thermal mass around the building and are very thermally stable. The downside is that soil moisture is a huge concern for below-grade structures, so below-grade portions of these buildings must be water and vapor tight.

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PRESENTATION

Choosing Standards and Best Practices for Environmental Design and Operation

JAMES M. REILLY

ABSTRACT. This paper contrasts the use of standards at two points of life in a museum: when it is built or retrofitted and as it is operated on a day-to-day basis. Even though the daily work of preservation requires thorough analysis, adjustment, and management of parameters, many organizations “default” to the preservation environment standard established at the outset of building a museum, library, or archives. This paper details the history of the preservation environment debate, describing the new tools that museums, archives, and libraries can use, especially in the practice of gathering and monitoring temperature and humidity data to establish benchmarks and make decisions. It is important to render null and void the notion that there is an ideal environment for museums such as 70°F/50% RH.

A shrunken head from the National Museum of Denmark in Copenhagen illustrates the complexity and diversity of real-world collections. Its collections managers must prioritize among chemical, biological, and mechanical hazards in conducting risk assessments and setting environmental standards.

Museum environmental standards are our guideposts, and they arose for good reasons: to meet the need for guidance when planning museums or thinking about the adequacy of conditions and for some form of authority. Standards have become concise statements of best practices and have grown to be more reference, with few or no tables.

Standards play an important role at two points in the life of an institution: the design/retrofit stage and the operations stage. Design/retrofit is a time-bound project, conducted by external architecture and engineering firms and overseen by construction managers who are project oriented and have a capital budget. At this stage, standards serve the purpose of authority documents (what others have thought and done) and represent normative definitions of best practice for both the client (the museum administrator and collections manager) and the designer. Environment is seen in the context of architectural programming: what the building is for, who will work in it, what they will do, and what parts are for storage, exhibits, research, etc. The design professionals are trying to understand what is wanted and what they have to do, keeping in mind code conformance such as how much outside air is minimal for a building that people will be in.

By contrast, the operations stage is continuous. Once the institution takes control of operating the building and systems on a day-to-day basis, standards serve as guidance to collections care and facilities managers and upper management as to how to actually go about it. Operations have become a collaborative, cross-disciplinary process. Because fiscal health is affected, it is essential that these disciplines that traditionally have not known each other's business work together. In the operations stage, one must diagnose the quality of the environment with respect to preservation and manage the performance of systems while meeting goals of sustainability and fiscal responsibility. To do that well, "industrial strength" data gathering and analysis are needed to translate the ideas behind best practices and standards to decision making. The bottom line is that if you are going to be concerned with the goals of stewardship, sustainability, fiscal management, and global responsibility, you need monitoring and analysis tools in the operations stage.

Standards have tended to reflect more the needs of design/retrofit than operations. With that in mind, it is important to drive a stake through the heart of the notion that there is an ideal environment for museums such as 70°F/50% RH.

Standards have evolved away from simplistic “received wisdom” embodied in short tables of numbers. Now, standards are a management strategy in which hard numbers have disappeared and in their place is a continuum of risk. The recently published UK Publicly Available Specification (PAS) 198 (British Standards Institute, 2012) has no tables at all. Rather than telling us what to do, standards now tell us what *not* to do. We all agree that at the extremes of relative humidity there are increased risks to collections, but the challenge now lies in where to be in the middle. PAS 198 and chapter 23 of the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) applications volume (ASHRAE, 2011) provide much information to guide us.

To paraphrase Dr. Martin Luther King Jr., “The arc of the environmental standards universe is long but it bends toward sustainable operations.” We have gone from seeing standards as prescriptive to being part of a coherent design and operating philosophy.

It is important to understand where the idea of an ideal environment for museums came from. Tight temperature and RH control originated in UK galleries, where people came to visit collections that were always on view and, where, consequently, human comfort temperatures were a given. Standards for an ideal museum environment came out of the fact that UK galleries had to control temperature tightly in order to achieve the desired RH, not because of a particular need with regard to preservation of collections.

The people who did the work that informs our notions of an ideal standard—Garry Thomson (1978, 1986) and, prior to him, Harold Plenderleith (1956)—were concerned with UK museums in large masonry buildings without elaborate mechanical systems and with collections of mechanically sensitive objects such as paintings and composite wooden objects. Garry Thomson, who was a giant of preventive conservation and called for investigation and understanding of the real behavior of environmental limits, is considered to be the source of the tightly controlled 70°F/50% RH ideal or “standard.”

Despite what Garry Thompson *actually* wrote and other conservation scientists have been saying for years, what we hear is: “blah blah blah temperature 70° ± 2° and blah blah blah humidity 50% ± 2%.”

What Thomson actually said about temperature is that it is only important in so far as it begins to influence RH and the mechanical or physical sensitivity of objects. Pressed to give recommendations, he suggested different summer and winter levels: 67°F ± 2°F in winter and up to 75°F ± 2°F in summer. In addition, he noted, “temperature must be controlled to control RH, but the level is dictated by human comfort. For fuel economy, different summer and winter levels are suggested.”

In storage areas or buildings closed to the public in winter, temperatures can be allowed to fall, but not to the point where condensation may occur on cold or unventilated surfaces. A lower limit of 50°F is suggested. So really, the ideal temperature from the “horse’s mouth” is anywhere from 50°F to 77°F.

What Thomson actually said about relative humidity is that it can be 50% or 55% ± 5% day and night throughout the year, adding that the level may be fixed higher or lower but for mixed collections a range of 45% to 60% is recommended. Thomson noted that the plus-minus

sign in RH control is based more on what we can reasonably expect the equipment to do than on any deep knowledge of the effect of small variations on the exhibit.

Moving ahead a quarter century, new research by Mecklenburg (1982) and Michalski (1991, 1993, 1994a, 1994b, 1996) undermined and explained the old “ideal” of 70°F/50% RH and began to explore true safe limits for even very mechanically sensitive objects. To understand the mechanical risks to collections, Mecklenburg and his colleagues (Mecklenburg and Tumosa, 1991; Mecklenburg et al., 2004) used finite element modeling to study component materials of objects (e.g., cottonwood used in a panel painting). They sought to determine the point where risk begins and thereby to define safe RH tolerances. They found wider variations in RH tolerance than was the accepted wisdom. They also explored the forgotten dynamic of temperature and how temperature-driven chemical reactions are major factors for all sorts of collections. In the degradation of organic materials via spontaneous chemical reactions, the reaction rate is dependent on the combined influence of temperature and RH.

This and other research helped move the standards, including (1) deemphasizing tight RH control and need for $\pm 5\%$ for most materials, (2) a closer look at the function of decay and how much risk is generated by one type of environment or another based on kind of material, climate, risk tolerance, architectural design, and sustainability considerations, and (3) an active environmental management approach that is more data driven and collaborative across disciplines within facilities management and collections care.

Chapter 23 of ASHRAE (2011) was written primarily for heating, refrigerating, and air-conditioning engineers with a bias toward design but is more modern in that it has much information not found in other kinds of standards. The handbook is revised every four years. The RH and temperature sections have changed little, but the pollution sections have developed substantially. PAS 198 from the British Standards Institute (2012) has less about design and more about management and operations, particularly section 3, which includes the following concepts:

- Good management is about accountability—it must be somebody’s job to look after the environment, and the institution itself is accountable for the environment it provides.
- Sustainability is important.
- An emphasis must be placed on monitoring.
- Every organization defines its own environmental specifications.

In other words, the answer to “What is the best environment for your museum?” is “You’ve got to figure it out for yourself.”

Furthermore, the modern understanding of how decay works and how you understand the notions of risk and costs for different environments in different climates is a process of making choices along continua. Many ideal environments reflect the needs of different parts of your collection, and you must prioritize among them. You are always choosing from a continuum of preservation quality/degree of risk and energy savings. *You* prioritize among mechanisms of decay. Going back to the shrunken head, are you more worried about chemical decay (leading to cooler temperatures), biological decay (mold or insects), or mechanical or metal corrosion? Which is most important to you, and what can you provide in an economical way?

PAS 198 has color bands to show continua of risk depending on conditions and the nature of collections objects. For example, the temperature chart helps you find the sustainability point that you want. Allowing for wider drift and adapting to the building and climate you have can be a more sustainable approach than fixed set points throughout the year. In sum, standards today such as PAS 198 do not specify environmental choices that are optimal; at best, they define scenarios of excessive risk, and it is up to you to decide what is optimal.

At a large institution such as the Smithsonian, there is an inherent managerial limitation in taking the approach of an institution-wide range of allowable temperature and RH values. That is, within any given range there will be better and worse choices in terms of preservation quality, stewardship, energy consumption, and incremental improvement.

A performance-based approach with “industrial-strength” data gathering allows you to bring together and leverage expertise within the organization, quantify risk, and get real-world feedback. You cannot manage what you cannot measure.

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PRESENTATION

An Overview of a Process and Specification: The British Standards Institute Publicly Available Specification (PAS) 198, "Specification for Managing Environmental Conditions for Cultural Collections"

JONATHAN ASHLEY-SMITH

ABSTRACT. This paper provides an overview of the origins and development of PAS 198, explaining the nature of a Publicly Available Specification, touching on the working methods and mindset of the team that created it, and the style and content of the finished product. Some of the drawbacks of the production process are described, and feedback after the first year is analyzed. The primary aim is to explore how much of the content and philosophy a large and diverse organization such as the Smithsonian can make use of. As with the presentation on which it is based, this paper is written from personal experience and expresses a personal point of view.

Introduction

PAS 198 (British Standards Institute, 2012) expounds a new way of thinking about environmental standards.¹ It does not tell you what to do, but it provides you with a framework for thinking about what you need to do. It also provides the route to a wealth of relevant information in the form of references to key publications that provide the evidence base to support preservation decisions. It encourages institutional autonomy by declaring that policies must be created and owned by individual institutions based on local needs, local philosophies, and the organization's own budgetary constraints.

It may not be possible for an institution outside the United Kingdom to use the document without some local interpretation. It is written in a language unique to the British Standards Institute (BSI) and was conceived largely by people familiar with British institutions and the British climate. Whatever the structure, most of the references and some of the words and diagrams are universally understandable and applicable.

If you want to recreate something in the image of PAS 198 that is completely relevant to your local constituency, I would advise a simplification of the development procedure and suggest that a bit more attention is paid to the topic of energy use.

British Standards Institute

The British Standards Institute, despite its parochial title, is a global organization eclipsing smaller standards organizations worldwide. Its website is available in 16 languages. Its mission statement, “BSI helps organizations make excellence a habit,” goes beyond standardization for its own sake. Its headquarters in London has numerous meeting rooms in which you will find groups of specialists determined to regulate different aspects of their varied professions. The altruistic professionals have the motivation and they do the work. They pay BSI to provide conformity of style and language and to gain an internationally recognized mark of authority. The BSI owns the copyright and keeps the profit from sales.

The BSI is a secretive organization, and members of the working and steering groups are asked to sign a declaration that they “shall not make any public statements about their participation in the work of the Steering Group or Review Panel and shall not make use of any material or information of which they become aware through their role as a member of the Steering Group or Review Panel.” Therefore, this paper cannot be a totally explicit exposé of the process.

The PAS as a Standard

It is best not to try to interpret the acronym PAS (Publicly Available Specification); treat it like one of those organizations or phrases such as V&A, C&A, and NATO that are more familiar abbreviated than fully spelled out. The *S* hints at it being a standard, which it is not, but then it is not really a specification either.

The important thing to know about a PAS is that the process enables standards to be developed rapidly, which is why this format was chosen in this particular instance. The difference between a PAS and a full standard is the degree of consensus—in a British standard, all stakeholders have to reach consensus on the technical content, whereas a PAS can be open for comment. A PAS may be considered for further development as a British standard, or it could become part of the United Kingdom's input into development of a European or international standard.

There are several caveats associated with a PAS:

- A PAS may take the form of a code of practice, lending guidance and recommendations. However, it should not be quoted as a “specification,” with special care to avoid misleading claims of compliance.
- If an organization wants to claim compliance with a PAS, it must justify any action that deviates from the recommendations.
- Compliance with a PAS does not confer immunity from legal obligations.

It is important to understand the vocabulary used in the PAS and in BSI standards in general. Degrees of insistence are implied by different auxiliary verbs.

- *Shall* denotes requirements—what the issuer insists you do.
- *Should* expresses a recommendation—something that would be good for you to do.
- *May* is used to express permissibility—something you are allowed to do if you want.
- *Can* is used to express possibility—a consequence of an action or an event.

For instance, “the usable life of collection items *can* be prolonged by means of preservation measures.”

An early draft of PAS 198 had the title “Specification for Environmental Conditions . . . ,” which might suggest that one *should* have 50% ± 5% RH. The title later became “Specification for *Managing* Environmental Conditions . . . ,” and consequently, the *should* refers to what one must do to manage, and 50% ± 5% RH becomes something that one *may* do.

The concept of a PAS as guidance was familiar in the British heritage sector. PAS 197:2009 (BSI, 2009) is a code of practice for cultural collections management that says that cultural collections organizations *should* have a collections development policy, a collections information policy, a collections access policy, and a collections care and conservation policy, all documented and approved by top management.

A Brief History

In the period running up to the publication of PAS 198, two UK research funding bodies (the Arts and Humanities Research Council and the Engineering and Physical Sciences Research

Council) had collaborated to fund heritage science projects. One initiative was the formation of research clusters, one of which was called EGOR: Environmental Guidelines: Opportunities and Risks. The EGOR cluster, led by Nancy Bell, head of collection care at The National Archives, held three workshops that looked at the ramifications of existing environmental standards on collections, buildings, and users. Several members of EGOR went on to join either the working group or the steering group for PAS 198. Stefan Michalski and I had the privilege of serving on both the steering and working groups, although it must be added that we never physically met during the process.

Both EGOR and PAS 198 explicitly credit the motive for their creation to the statement from the UK National Museum Directors' Conference (2009): "Museums need to approach long-term collections care in a way that does not require excessive use of energy, whilst recognising their duty of care to collections. There is general agreement that it is time to shift museums' policies for environmental control, loan conditions and the guidance given to architects and engineers from the prescription of close control of ambient conditions throughout buildings and exhibition galleries to a more mutual understanding of the real conservation needs of different categories of object, which have widely different requirements and may have been exposed to very different environmental conditions in the past."

The final meeting of EGOR generated a list of six research priorities: science of material tolerances, modeling the built environment, energy use, biodeterioration, new technologies, and values and human adaptation. The EGOR findings enabled Nancy Bell to call for a review of British Standard (BS) 5454:2000, "Recommendations for the Storage and Exhibition of Archival Documents" (BSI, 2000). The standard had come under serious criticism as it is difficult to meet its stringent environmental requirements without introducing invasive, expensive, energy-consuming HVAC systems. If the standard had allowed for the temperature to drift, it would have been easier to control the RH within the guidelines. Moreover, even though it was intended for use only with archive material, BS 5454 was consistently and inappropriately being applied to other sorts of collections.

This inappropriate application led to the call for a standard that would allow examination of more agents of deterioration and a wider range of collections. The PAS mechanism was chosen for reasons of speed.

The Core of the PAS

The PAS uses a diagram of concentric rings similar to Figure 1 to explain its guiding philosophy. Cultural collections sit in the center. The outer circle contains the traditional environmental considerations (temperature, RH, light, pollution). Between the two are less traditional considerations (material sensitivity, intended use, expected lifetime, energy economy). The diagram exposes one of the weaker parts of the project. Because the cultural collection is placed firmly at the center, the building envelope and existing hardware are not given sufficient weight, if they are considered at all.

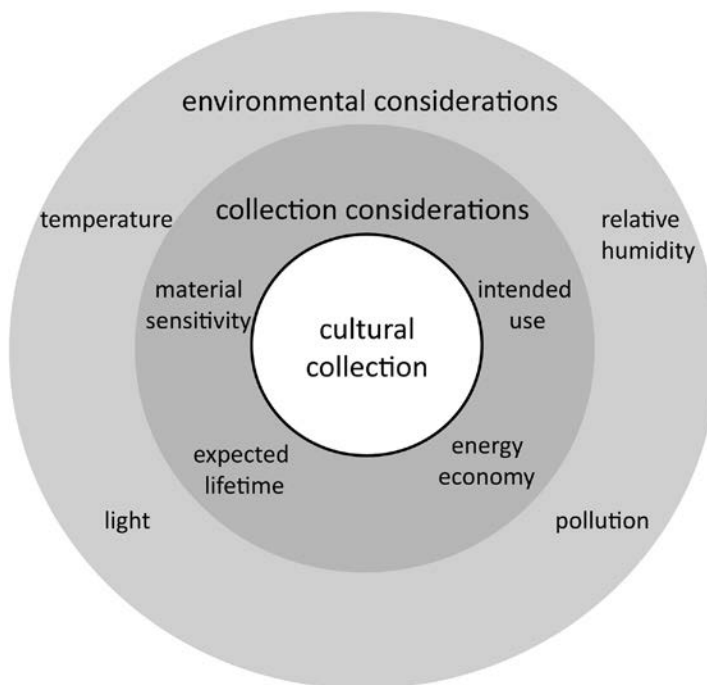


FIGURE 1. The PAS uses a similar diagram of concentric rings to explain its guiding philosophy.

The primary drive of PAS 198 is given in the following statement (emphasis added):

The organization *shall* develop an environmental management strategy for the collection. The strategy *shall* include a statement of the expected collection lifetime and the energy demand arising from the environmental conditions needed to achieve this, taking into account the sensitivity, significance and use of the individual collection items. NOTE: The strategy *should* make clear the balance the organization intends to aim for between preservation requirements, usage and display, and energy economy. (BSI, 2012)

This balance is the most difficult thing to achieve, namely, the need to optimize four competing and interconnected outcomes: stability, cost, sustainability, and accessibility (Figure 2). In such a complex system, the optimal solution will probably be suboptimal to at least one of the components.

The project organization for the PAS, although appearing from the diagram in Figure 3 to be logical and systematic, was in fact complicated and bureaucratic. At the top level the project director gave shape and direction to the project. The technical author was responsible for collating texts and giving shape to the final document. The BSI project manager ensured that the work stayed on track, that the language was suitable, and that the workings of the groups were kept confidential. The steering group of eight people made broad indications of scope and direction and checked progress. The working group of around eight people did the real work, supplying technical detail and appropriate citations. The review panel consisted of a

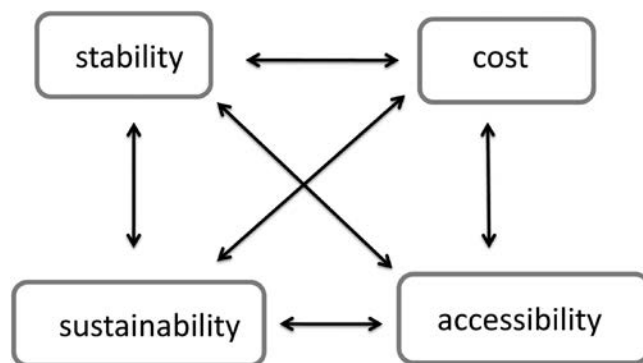


FIGURE 2. The PAS advocates for optimizing four competing and interconnected outcomes.

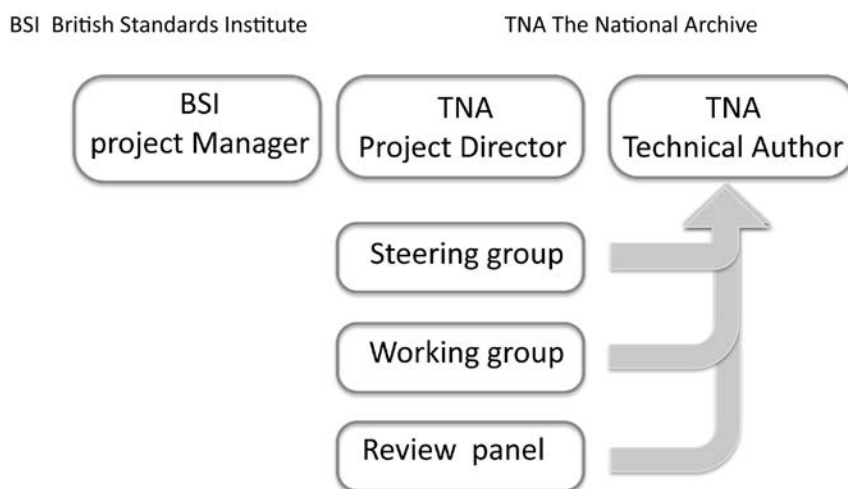


FIGURE 3. Organizational diagram for contributors to the development of PAS 198.

large number of individuals and institutions that were asked to read preliminary drafts, make comments, and suggest corrections and possible additions.

There were numerous channels of communication, formal and informal, overt and covert. But all iterations of content and comment went through one person, the technical author, whose job it was to select which version of the truth would appear in the final document. Needless to say, the technical author's decisions were not always popular.

Structure

The document opens with an introductory section, which includes a historical overview, a glossary, and list of related standards. The first substantial chapter (titled “General”) gives the main nontechnical managerial thrust. In it are sections on assigning responsibility, developing strategy, data collection, risk assessment, environmental specification, environmental monitoring, energy economy, and data documentation. Each dictatorial “shall” statement is supported

by a note containing helpful “should,” “may,” and “can” sentences and references to relevant literature and to other parts of the document.

The main technical section consists of the four chapters on temperature, relative humidity, light, and pollution, with many “shall” statements on how these should be considered and managed. Then come several informative annexes and a comprehensive 15-page bibliography.

Style

The PAS followed a tricky path with a style somewhere between a comprehensive educational textbook and a tersely stated directive standard. Although it contains a lot of text, it also has clear statements that encapsulate key points, for instance, “Light: specification of illuminance is always a compromise between preserving the collection item and making it clearly visible.”

The pollution section is different from the others in that it advocates an “evaluate-monitor-mitigate” approach; in other words, do not flood the place with monitors before you know you actually need them, a situation that is too late to rectify these days with RH and temperature monitoring.

Two of the annexes use brightly colored charts, visual aids that attempt to encapsulate the limits to allowable ranges of temperature and humidity. They indicate how it is possible to drift within ranges to minimize energy consumption; however, this drift is constrained by human comfort, UK law, and common sense (you may not freeze employees and would not want to freeze your water pipes).

Delay

Once the PAS was ready for publication, a delay of several months occurred because of some behind-the-scenes attempts to modify the document or ban its use completely. During the hiatus the National Gallery in London entered the public debate by launching a new website (National Gallery, 2011) that described its own environmental and sustainability policy with a standard attributed to early gallery scientist Garry Thomson with refinements by gallery staff member David Saunders: 55% ± 5% RH and temperature of 21°C ± 1°C in winter and 23°C ± 1°C in summer.

The National Gallery rationale included the view that easel paintings are *exceptionally* complex in their material construction and that *unusually* stringent demands of environmental control are required to ensure their preservation. This policy undermines the work of Mecklenburg and other conservation scientists to date, stating “Real paintings are very much more fragile than experimental test models which significantly over-simplify the nature of the problem, particularly with regard to their complex mechanical behavior.”

The National Gallery asks an interesting question: “Is active environmental control in museums responsible use of energy?” Their answer is that it is a matter of definition. In this case, the policy states that “only ducted air-conditioning systems can provide safe conditions for long-term preservation of real paintings, and these systems will consume a proportion of the Gallery’s energy budget.” It is a fair point to make because they are trying to balance two

nonrenewable resources: old master paintings and a lifestyle that people in the West have become accustomed to. The PAS is meant to generate that sort of debate, asking “Which of these is the more important?”

Feedback

A year after the publication of the PAS document I collated some of the informal and anecdotal feedback I had received. Common complaints were as follows:

- It doesn’t tell us what to do!
- The concept of “lifetime” is difficult.
- The concept of “lifetime” is dangerous.
- The PAS is difficult to use in teaching.
- Scientific experiments do not reflect the real world.

The first point is easy to answer. Not telling you what to do is the unique new feature of the document.

The concept of collections lifetime does not have to be difficult. You need to agree on an admittedly arbitrary planning horizon of say 50, 100, or 200 years. Understanding the nature and environment of your collections, you need to predict the point in the future at which they will cease to be fit for purpose. Figure 4 presents several different scenarios relating to the fade-out point. Thinking about and planning for the inevitable are surely helpful rather than dangerous.

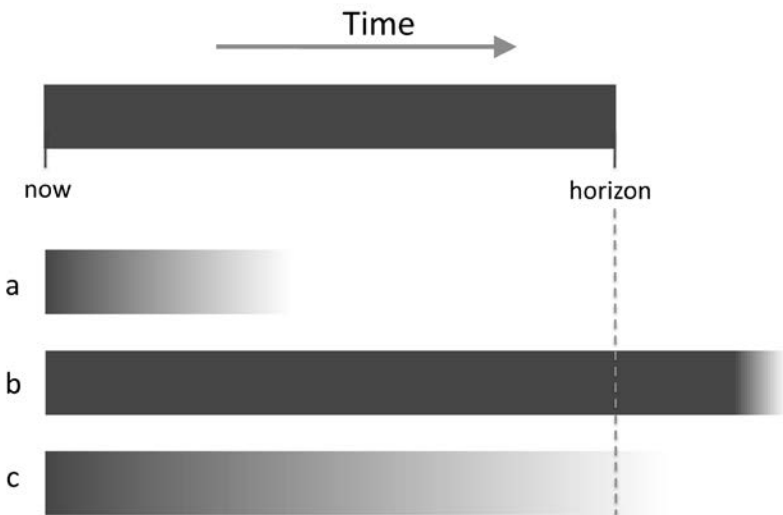


FIGURE 4. The concept of collections lifetime with fade-out points. In scenario a, the fade-out point comes before the planning horizon, indicating the choice of doing something about the lifetime or, if resources do not allow action, accepting that the fade-out point is the collection lifetime. In scenario b the fade-out point is beyond the planning horizon, indicating that nothing needs to be changed. In scenario c the fade-out point is somewhere close to the planning horizon, indicating nothing needs to be changed in the present because a review at set intervals may involve new information and a new starting point.

The PAS will appear difficult to use in teaching only if your previous approach has been to teach simple, easy-to-remember universal fixed numbers. The methodology of PAS 198 is ideal for teaching using case studies and group discussion. The actual document is not intended as a teaching text at student level:

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

With respect to scientific experiments, PAS 198 notes that:

Alongside empirical research, it continues to be important to take account of the experience of, and data collected by, conservation professionals who witness first-hand the changes to objects over time. (BSI, 2012)

Summary

Some key takeaway points about PAS 198 are as follows:

- It is very libertarian—it doesn't tell you what to do.
- It gives you a framework for thinking about what to do.
- It gives you the best set of tools that is available at the moment.
- It empowers you to follow your own local philosophy on sustainability or collections use and stay within your financial means. You can develop your own local compliance without being subservient to external normative pressures. You can devise your own conditions or your own criteria for different collections within your organization. "Compliance without subservience" could be a new slogan for collections care.

To achieve a locally satisfactory product, the procedure for information gathering and consensus building could be made simpler and more transparent. Energy considerations should be incorporated more fully. The need for training in topics such as collection lifetime needs to be recognized and budgeted for. As for the Smithsonian, it should certainly use the framework, some of the text and visual aids, and the tools that are publicly available.

Note

1. PAS 198 was sponsored by The National Archives in the United Kingdom, with additional sponsorship from Collections Trust, CyMAL: Museums Archives and Libraries Wales, a division of the Welsh government, and the Museums, Libraries and Archives Council. Its development was facilitated by BSI Standards Limited and published under license from the British Standards Institute. It came into effect on February 29, 2012.

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PRESENTATION

Sustainability: Climate for Culture

FIONA COUSINS

ABSTRACT. This paper demonstrates the challenges of retrofitting or designing museum spaces sustainably given the requirements of the preservation environment, highlighting several example solutions. Sustainability and green building goals are not just about energy savings but also about conservation of water resources, using sustainable building materials, coping with climate change, being a contributor to the built environment, and promoting operational sustainability.

From the perspective of a mechanical engineer, the $70^{\circ}\text{F} \pm 2^{\circ}\text{F}$ and $50\% \pm 5\%$ RH preservation environment design “standard” set points are ubiquitous in the museum world. Maintaining these set points is a major expense for museums but in some cases is required to allow loans from other institutions. The prevalence of these tight temperature and humidity conditions demonstrates that museum staff and conservators are reluctant to establish different set points in the absence of expert guidance on the effects of temperature and humidity variation on the preservation of collections, even though these tight conditions are clearly not necessary for many kinds of artifacts. From a sustainability standpoint, maintaining $70^{\circ}\text{F} \pm 2^{\circ}\text{F}/50\% \pm 5\%$ RH ($70^{\circ}\text{F}/50\%$ RH) when it is not needed is energy wasteful; in addition, mechanical systems and buildings that can meet these set points, within the tight variations specified, especially when cooling and heating loads vary widely, are complex. The need or desire to maintain these set points affects every piece of the building, including the materials used to build the building, the size of the mechanical system, and the energy costs associated with humidity and temperature control. The ubiquity of the $70^{\circ}\text{F}/50\%$ RH standard makes it difficult to implement operational protocols that conserve resources, such as seasonal shifts in environmental set points or reducing 24-hours-a-day, 7-days-a-week operation.

For the mechanical system to meet stated temperature and humidity set points the engineering team must understand all of the design conditions that might occur. These might arise as a result of weather or occupancy, for instance, when gallery spaces are filled with visitors with damp umbrellas or a large group of visitors moves together from gallery to gallery or the sun shines directly into the room. The system is then designed to provide $70^{\circ}\text{F}/50\%$ RH under all the likely design conditions. The more extreme these conditions are, the larger the system will be, with more variability expected over time and more complex controls.

A system can, of course, be designed for $70^{\circ}\text{F}/50\%$ RH and then operate at a more relaxed set of conditions to reduce energy costs; for example, a museum can choose not to run the dehumidifiers or to run them less. In this case, temperature control will be unaffected. Many things can be done to hold design conditions more loosely and keep energy costs lower, including changing target design conditions over the course of the year or allowing a wider variation in temperature. At the end of the day, however, if the suit is too big it doesn't actually fit. Installing and maintaining an HVAC system that can maintain tight temperature and humidity control and then operating it at a wider performance range is not money well spent.

Consider the types of environments and systems that influence design choices in the following buildings:



FIGURE 1. Former home of The Women's Library, London.

FORMER HOME OF THE WOMEN'S LIBRARY, LONDON. An archive (Figure 1) that does not have occupants can run very economically: the mass of the enclosing envelope and of the materials themselves helps to buffer temperature and humidity changes, and the only variable factor is the weather. The systems can be set to provide minimal fresh air to deal with chemical buildup and positive pressurization to reduce infiltration of outside air.

Once people are introduced to the space, they act as both a source of heat and a source of moisture, and the fresh air ventilation rate must increase. They may also need lights to examine the materials, which introduces even more heat to the archive space. The complexity of the system design arises from the research and academic need to allow people into the archive (Padfield and Jensen, 2011).

SAINSBURY WING OF THE NATIONAL GALLERY, LONDON, 1985–1986. As part of the commissioning of the mechanical system for this project (Figure 2), the temperature and humidity loads associated with a busload of visitors with damp umbrellas were simulated using electric kettles and light bulbs. Smoke bombs and a video camera were used to record the air flow patterns and to prove that the mechanical system could operate as designed.

ASHMOLEAN MUSEUM, OXFORD. Historic structures like the Ashmolean Museum (Figure 3) are often built from materials that allow moisture migration. This construction can make it difficult



Photo © The National Gallery, London.

FIGURE 2. Sainsbury Wing interior.



Photo © Ashmolean Museum, University of Oxford.

FIGURE 3. Forecourt of the Ashmolean Museum, University of Oxford.

to achieve tightly controlled temperature and humidity conditions because moisture cannot be contained within the conditioned space. This difficulty in controlling moisture may result in significant additional energy use, especially in winter when humidification is needed. It may also result in damage to the building envelope or mold if moisture within the building materials freezes or condenses. Great care should be taken with historic buildings if a decision is made to gain additional control over its internal environments.

MUSEUM OF CONTEMPORARY ART SAN DIEGO. This museum (Figure 4) adopted a historic train station as new gallery space. The building envelope allowed moisture migration, so a decision had to be made about whether to try to control humidity. The museum decided to keep the existing open space within a broad range of 65°F–80°F, comfortable for most visitors coming from outside, adequate for much of their collection, and relatively inexpensive to operate. The requirements of insurers and lending institutions for 70°F/50% RH are met in small exhibition spaces that are enclosed with vapor barriers and are served with systems that allow humidity control.

To implement design choices in a sustainable way, Arup, a global design and engineering firm, draws on six major concepts (Figure 5):

1. Aiming for carbon neutrality, through energy saving and the use of renewables
2. Minimizing water use by collecting and reusing water



FIGURE 4. Museum of Contemporary Art San Diego, Strauss and Farrell Galleries, downtown location, San Diego, California.



Courtesy Arup.

FIGURE 5. Arup's six sustainable inquiries.

3. Adopting sustainable materials, through use of recycled content, local content, selection for reduced embodied energy, or life cycle analysis
4. Adapting to future climate change through system sizing, building siting, or other measures appropriate to the location
5. Being a positive contributor to the community and the built environment
6. Operating in a sustainable way through energy use reductions, material supply choices, and other management efforts

Some of these concepts are clearly aligned with the mission of many museums—much of the work of museums is to contribute to the community through the provision of meeting places for the public to see and discuss material important to culture or heritage. The materials selected are often chosen to be safe for sensitive exhibits and are also benign for humans. Keeping operating costs down and reducing energy use also support museums' overall mission, but the concepts of carbon neutrality and sustainable operations pose specific challenges for museums and galleries.

Reducing energy use is a significant component of achieving carbon neutrality and sustainable operations goals, and museums are typically high energy users because they run 24 hours a day, 7 days a week, and target 70°F/50% RH conditions at all times. Adding to the sustainability and operational challenges is the fact that museums tend to have many stakeholders, including donors, directors, curators, conservators, and visitors, whose purposes may be at odds. For example, directors often want to invite donors to eat and drink in the gallery spaces, and the heat and moisture resulting from the food and the dense occupancy can be a challenge in a closely controlled environment. In some cases, this scenario determines the design cooling condition and sets the size of the mechanical systems.

The first question to ask when designing a museum or gallery with a focus on operational sustainability is, What do you want your building to do? Is it an iconic building or an art-centric space? Can it be both? Buildings like Centre Pompidou in Paris, the Royal Ontario Museum in Toronto, and the Guggenheim in Bilbao are very much about using iconic architecture to draw people to make a social connection with the building as well as what is inside it. This decision will influence the building form, its envelope, and its program and is likely to have the biggest impact on building sustainability.

The second question is, What do you want your visitors to get from the visit? Is the visitor experience to be a curated or naturalistic experience? This decision helps determine whether a museum will use electric or natural light. The typical European approach is to be naturalistic in design, with enough natural daylight to see the pictures in large open rooms. The North American approach is generally more curated in that exhibitions are frequently designed for display in dark rooms with highlighted objects and a focus on individual works. As heat from the sun can be a very large proportion of the peak cooling, any building that is designed for natural light must also consider how to screen direct sun and insulate the building envelope so that this load is kept as low as possible and the variation in cooling load over time is minimized. The museum may also decide to allow some variation in internal conditions in some spaces so that they can be sunlit.

Another design question has to do with directness of experience versus technology mediated. Museums are adding greater dimension to the visitor experience through the use of electronic devices such as phones or interactive displays that provide additional information and allow the visitor to personalize their experience. The use of electric-powered devices typically leads to higher levels of energy use than traditional exhibits, but these devices do not require stringent environmental conditions. Changes in the use of technology affect both the size and variability of the cooling and heating loads and alter the way in which the building and HVAC systems need to respond to maintain the design conditions. The first step is to make these devices as energy efficient as possible, and other effects may be managed by allowing different conditions in different spaces, depending on the use. These exhibition innovations may require changes to system zoning, additional control intelligence in the building operating systems, and changes in the way the maintenance and curatorial teams operate the building.

Another consideration for building sustainability is the trade-off between flexibility and low initial cost. On one end of the spectrum are spaces like the Richelieu Wing of the Louvre, a large, nonflexible gallery where everything—how it is used, how the light falls, how the exhibits are shown—is mostly fixed. At the other end are highly flexible temporary exhibition spaces where partitions are regularly moved to suit different exhibitions. Designing systems to allow for relocation of partitions at reasonable costs usually requires the development of a modular ceiling and floor layout and the addition of HVAC, lighting, and fire protection zones.

A key facet of sustainability is to retain and reuse building materials to reduce the environmental impact of the building. It is often less expensive and culturally interesting to reuse buildings for gallery space rather than building from scratch, and there are many museums and galleries that occupy repurposed buildings. These include the Museum of Contemporary Art in San Diego, mentioned earlier, which is in a disused train station, and Dia:Beacon, which is in an old factory. Unfortunately, there are often issues with the envelope of found spaces: the envelopes may be leaky or poorly insulated and are unlikely to be able to contain moisture within the space, making energy bills high and humidity control difficult. Leakiness is often solved through repairs, but the addition of a vapor barrier and insulation may cause condensation within the building envelope, especially in climates with wide seasonal or daily temperature variations, and this in turn can damage the building or create the conditions for mold growth. Depending on the types of exhibit planned, it may be appropriate not to use the 70°F/50% RH standard in these types of spaces, which was the approach taken at Dia:Beacon.

The most direct link between operational costs and protocols and sustainability is the need to balance the requirements for collections conservation with the need to minimize operating costs for energy. As previously noted, the conservation requirements that lead to high energy costs are the maintenance of a stable 70°F/50% RH standard. In addition, energy costs are increased with the use of carbon filters to control pollutants. There may also be energy implications arising from the need to protect objects from ultraviolet radiation and for the limited illumination exposure that some artifacts are allowed.

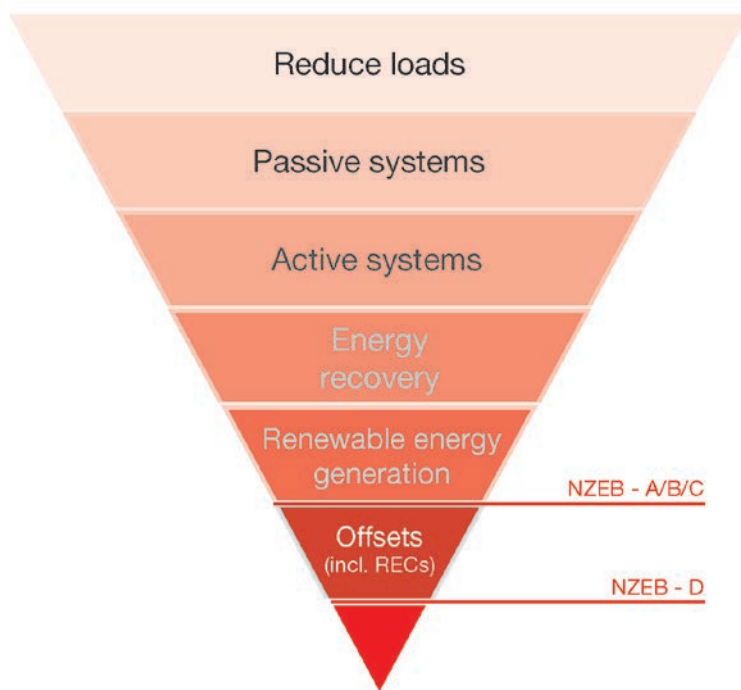


FIGURE 6. Energy reduction process. ©Arup. NZEB: net zero energy building. The definitions of NZEB A–D are included in Shanti Pless and Paul Torcellini, “Net-Zero Energy Buildings: A Classification System Based on Renewable Energy Supply Options” (Technical Report NREL/TP-550-44586, National Renewable Energy Laboratory, Golden, CO, 2010), http://www.nrel.gov/sustainable_nrel/pdfs/44586.pdf.

Reducing operating energy follows a well-established process (Figure 6). First of all, the loads must be reduced, perhaps through relaxation of design conditions or controlling particular activities like gala events so that they occur on nonextreme weather days. Load reduction can also be achieved through controlling sunlight entering the spaces, good insulation, appropriate lobbying of entrances and exits, distribution of energy-using exhibits, and crowd control. Once the loads have been reduced, the systems can be designed to reduce the energy use first through passive means and then through active means and energy recovery. If the goal is for zero operational costs, then solar power or wind power may also be considered.

Many creative solutions to heating and cooling gallery space with the least possible energy exist, even where stable conditions are required. The Museum Brandhorst, Munich, is a top-lit flexible space gallery with under-floor air supply. This arrangement allows for great flexibility in partition layout without making system changes. The galleries also have “activated” slab walls that have water pipes running through them, containing chilled or heated water. The water in the pipes provides the effect of thermal mass, absorbing peaks in solar or occupant load. When the “peaky” heat gains are absorbed by thermal mass or pipes that create a similar effect, the loads on the air system are lower and more consistent. This reduction simplifies the air system design compared to an “all-air” system, perhaps allowing a constant-volume system, and

reducing the variation in supply temperature, which simplifies the controls. Systems like this, in which the cooling loads are shared between air and water systems, typically reduce the size of the air-handling systems and ductwork and the associated space requirements. In many cases, this load sharing can reduce capital costs overall, although the mechanical system costs may be similar for both types of systems.

Another approach is found at the Kimbell Art Museum in Fort Worth, Texas, and the High Museum of Art expansion in Atlanta, Georgia. At both of these museums, cooling is provided through an all-air “displacement” system that distributes air via under-floor air distribution. This approach provides good flexibility for repositioning partitions and good comfort for the occupants. Heat tends to accumulate near the top of the galleries with displacement systems, and the 70°F/50% RH conditions are not always maintained at high levels. This effect can be mitigated by building galleries with high ceilings so that the off-conditions space is above the highest-placed objects.

To conclude the discussion of energy and sustainability and its relationship to museums and galleries, here are a few major steps that should be considered in the design of museum and gallery space:

1. Consider whether the 70°F/50% RH standard can be relaxed in any parts of the building or at any specific times. Wherever possible, reduce the variability in load over time by minimizing peak loads and reducing fresh air rates during unoccupied hours.
2. Reduce the heating and cooling loads on the building by controlling how much sun enters the building and insulating it well. Use efficient lighting systems, and turn them off whenever possible.
3. Select the most energy-efficient systems for temperature and humidity control. Start with passive approaches such as thermal mass and then look at active systems such as activated slabs, mixed air-water systems, and under-floor air distribution where possible. Aim for high levels of heat recovery, especially where simultaneous heating and cooling are needed for tight humidity control.
4. The most sustainable design for any museum will depend on the collection and the conservation requirements, the planned visitor experience, the need for flexibility in layout, the architectural design, and the ability to support operating expenses over time.

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PRESENTATION

Panel Discussion—Relationships, Respect, and Trust: Collaboration among Museum and Facility Professionals

MODERATOR:

CECILY GRZYWACZ, Facilities Scientist, National Gallery of Art, Washington D.C.

PANELISTS:

JONATHAN ASHLEY-SMITH, independent teacher and consultant
(formerly Head of Conservation, Victoria and Albert Museum)

FIONA COUSINS, Principal, Arup

MICHAEL HENRY, Watson & Henry Associates/University of Pennsylvania

STEFAN MICHALSKI, Senior Conservation Scientist, Canadian Conservation Institute

JAMES M. REILLY, Director, Image Permanence Institute

R. ROBERT WALLER, President and Senior Risk Analyst, Protect Heritage Corporation

The Moderator's Postsummit Reflections

Collaboration—it is about relationships, respecting each other, and trusting that we all are working for collections preservation. Through our relationships we learn to respect each other's areas of expertise and contributions to the museum environment, and we earn trust. Each quality builds on the other. We work together to develop relationships. We approach each other with mutual respect so that we can listen and understand the concerns and advice. We trust that there is significance to the concerns, that the advice is feasible and relevant, building relationships to get what needs to be done accomplished (Figure 1).

We all come to this table of collaboration with different areas of expertise: science, art, design, management. We achieve that expertise by different education and different backgrounds. Then there is the different professional lingo. Not only does this vary by profession, but regions of the country and internationally.

Preservation of collections melds conservation, management of the facility where those collections are housed, and leadership of the institution. The stakeholders range from the professional engineer to the custodial worker, the conservation technician to the curator, the architect to the preparator, the framer to the artist, director, the trustee, the patron, the visitor. We all must work together to preserve collections.

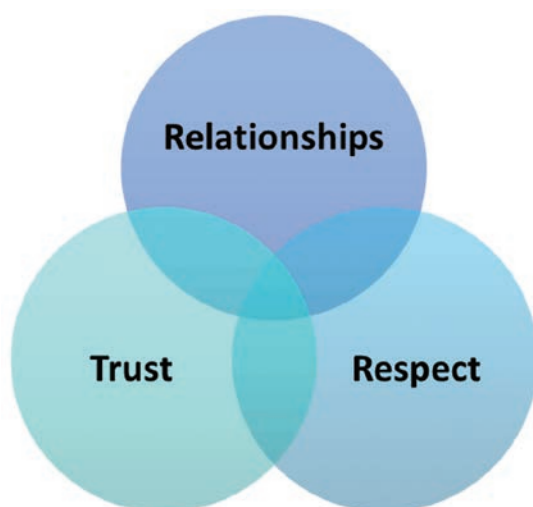


FIGURE 1. Collaboration is about relationships, respecting each other, and trusting that we all are working for collections preservation. Through our relationships we learn to respect each other's areas of expertise and contributions to the museum environment, and we earn trust. Each quality builds on the other.

Preservation environments are a function of geographical location, the building, and the artifacts. The complexity of each of these factors means that there is not one set of parameters that can be specified unilaterally. Even within the same location or climate zone there are differences in the types of buildings and climate control systems. Once inside a building there are different types of spaces: galleries, storage rooms, display cases, and public spaces with no objects on view. We know that each type of collection can have separate requirements for stability and preservation. For example, we know that we should minimize light exposure for watercolors, whereas light damage to marble statuary is less of a risk. Finally, at the individual object level more stringent environmental controls may be required. Inorganic colorants are more light stable than organic colorants. Because of these global, local, and specific parameters, collaboration between diverse experts, such as those on this panel, is mandatory.

Summit Panel Dialogue

Question: *What are the perspectives of different professional specialists responsible for building and managing the preservation environment? What are the commonalities?*

Grzywacz introduced the panel topic of collaboration among facilities, conservation, and collections management professionals.

Collaboration is built upon relationships, trust, and respect. If you are on the collections side, how do you know when to go to the facilities people if there is a possible problem with the collection and vice versa? We need to stop worrying about asking people needless questions because we will eventually learn what we can help each other with.

Grzywacz to Robert Waller (referring to his presentation on risk management where facilities managers are responsible for source, collections personnel for path, and conservation science for helping us understand what the effect could be): *We each perceive risk differently, so how can we make sure that we each understand the risks, which are very different in the three branches?*

Waller: We all perceive risks differently and there are many common perceptual biases in risk. One is voluntariness of risk—if collection managers are able to control a risk by themselves, they will perceive it as much lower than if they had to rely on facilities personnel to deliver the protection. The trick is to come up with rational predictive numbers (e.g., we expect that 5% of the collection will experience loss). That provides a concrete common understanding, even though it may be difficult to achieve. As long as we only rely on our passion or intuitive sense of the risk, there will always be big differences depending on our perspective. We want to get to concrete numbers, even if they are approximate.

Grzywacz to Waller: *If I'm the collection manager and I believe that I can handle that risk and don't share that with facilities, how will facilities learn about that potential for risk?*

Waller: We strive to be comprehensive in identifying and defining risks. To do that requires very good documentation so that it is clear to everyone if there is risk of an excursion to a high RH and how that is interpreted for each of the collections, i.e., what are the most vulnerable

objects and what is the median object, is it low vulnerability or is it also quite high? In that way you construct a profile based on the variability of the collection and the nature of the materials.

Audience Question: *On a collaboration continuum, with facilities, collections, and science, where do vendors (e.g., HVAC components), contractors, and leased building managers fit in?*

Reilly: It varies; each one is a different case. For example, in leased space people feel they have little control over things, making for what is often a fraught situation. Vendors operate a lot of buildings, and they should feel comfortable getting together with conservators; likewise, the management of the institution should feel comfortable having conservators talk to whoever is running the building to work things out. It does become more difficult when the parties involved don't report to the same organization. At my university, for example, the provost is the highest academic officer and the vice president for administration is the boss of the facilities organization, so the onus goes to the top to facilitate that cross-disciplinary conversation.

Henry: If you know you are going to put a collection environment in leased space, the owner/operator of the building has to be brought into a collaborative discussion before the lease is signed rather than afterward when the cost, profit, and lease rates are set. With respect to vendors, if a major specialized piece of equipment is being installed such as a dehumidification system, the vendor needs to be brought in during design and made aware of what the expectations are for that equipment once the project moves into operation.

Cousins: As Reilly said, the problem with operations is that it is not a project. When you are designing a building, making a lease, or doing a renovation, you have a project, and you know how to deal with vendors or manufacturers because it is part of the design process. It becomes an issue when they are not part of the design process; at that point there needs to be more collaboration than I currently see.

Grzywacz: *How can you zone or isolate areas within a building that are all on view and that have different exterior wall construction?*

Cousins: In order to get close control you have to respond to what's happening in the part that you are influencing. So you must have a zone for every room, sometimes multiple zones in a room. We are always dealing with controlling temperature and RH separately for spaces that are interior, exterior, east facing, south facing, north facing, brick, aluminum panel, glass—it is just part of the design work.

Henry: You can design for that, but in many museums one can observe that doors intended to maintain zone separations are propped open for various reasons. It is virtually impossible to maintain that separate zone performance if the museum staff allow doors to be propped open.

Grzywacz: *Is it an education process—explaining the reason why we keep this door closed? We are all so busy running around and with new people coming on that we don't take the time to do that. It's a challenge to understand how each building works for collection preservation.*

Cousins: Within the project process there are two stages of information handover. The first is where the institution says what it wants and the design team runs with it. In the second stage the designers deliver the building design and instructions on how it will operate. Neither of the stages of information transfer is done very well. Moreover, in new buildings, the facilities maintenance people often have not been hired yet, so there is no one to give that information to. It is not part of the design handover or standard services and takes greater effort to propagate that institutional knowledge.

Reilly: The building design process is complicated in that it disaggregates into ducting, piping, electrical, etc., and there are only a few people with an overall holistic sense of how it is supposed to work, making the first handover doubly hard. In addition, the commissioning process can be misleading in that the building and system commissioners have to verify that piece x, y, or z is working, but that does not provide the essential knowledge of how to operate. By the time it is fully handed over the holistic understanding is lacking.

Grzywacz: *How do we maintain and continue that knowledge in existing buildings?*

Cousins: Universities do this best. Because they have a large number of existing buildings that they manage over time, they have a facilities team that does technical review for every project and makes sure it is something they know how to maintain and complies with their standards. The facilities team's role is to make sure there is an ongoing dialogue with the designers so that they understand what is wanted.

Reilly: There is a strong need for documenting how everything is working on the facilities side. You know things are working well if you walk into a mechanical room and can immediately tell what is what—like an organized versus a messy bedroom.

Audience Question: *How is the amount/need for outside air determined? Is it based on a formula or actual oxygen and carbon dioxide levels in the building? Wouldn't it make sense to base the need for fresh air on actual levels of CO₂, particularly in high-air-volume, low-occupancy areas such as storage?*

Cousins: Carbon dioxide is difficult to measure; you need a lot of sensors in different areas. The amount of fresh air in gallery space is determined by outside and inside conditions and the number of people. It is usually kept to a minimum based on code. Sometimes during unoccupied times it goes lower and is based on pressurization.

Henry: In storage areas, you can go to low levels of outside air but need to be aware of the potential for off-gassing of collections, for example, industrial collections or natural history collections in solutions.

Audience Question: *In mixed material collections, what is the recommended process for determining appropriate temperature and RH levels?*

Michalski: Use a risk approach—if you are looking for a single magic number, you will get frustrated. It is better to ask where the most damage is happening for certain conditions and try to avoid that. If a sweet spot emerges, you're lucky. There will probably be several sweet

spots where you have to trade off one collection or issue against another, and you have to have a metacriterion to determine which one you prefer.

Within any risk assessment you need to think about significance. There are two components that make a risk large: one is the material science and the probabilities it suggests, and the other is whether it is a precious object relative to other things. If you know that your collection's significance resides to a greater degree in some objects than in others and the material risks are similar, then clearly the priority is to avoid damage to the more precious objects. So you start with the sensitivities/susceptibilities of the collection and where, if it pertains, you have a higher percentage of your whole collection value. If that is not an issue, you can focus on the material science. It can become a feasibility issue, and some decisions based on resource constraints can generate more risk. In summary, do not look for a magic bullet that hits the bull's-eye for all collections. You need to ask where the big, red, nasty spots are—identify and avoid the red danger zones rather than try to find the greenest zones.

***Audience Question:** With regard to thermal comfort versus collection preservation—explain to a noncollections staff member why preservation environments may not always be equivalent to human comfort?*

Reilly: Collections are dead, they don't feel hot and cold and like being cold because it slows down chemical reactions (though the point is conceded with regard to zoo collections).

Ashley-Smith: The National Gallery went from 19°C to 21°C as its basis for human comfort, whereas the Medieval Gallery of the Victoria and Albert Museum has temperatures in the winter of 16°C and lower and nobody complains. We have to define human comfort in a different way than traditionally where people are accustomed to being able to wander around in T-shirts.

Reilly: There is an ISO standard to calculate the probability that a given individual will be comfortable, taking into account level of activity, what they are wearing, the mean radiant temperature, humidity, etc. You get a probability that x% of people will feel comfortable in y set of circumstances.

Henry: We know less about how to define what range of temperature and RH is appropriate for human thermal comfort than we do for collections. ASHRAE has studied this—the initial presumption was human thermal comfort in the heating season; then with the onset of air conditioning it became how to define comfort in the cooling season. There is now a tremendous amount of research on adaptive behavior in human thermal comfort where there is either no air conditioning or less air conditioning due to energy saving. The research is showing that the tolerance span for human thermal comfort is larger than previously thought.

Reilly: The Library of Congress Fort Mead facility is 50°F/30% RH. People were basically wearing moon suits of inch-thick fleece. People working at a similar 50°F/30% RH facility at Cornell University in Ithaca, New York, are more adapted, wearing sweaters, with some people running forklifts in T-shirts.

Ashley-Smith: To some extent it has to do with training. If you say to people that the temperature is for the good of the collection they've come to see, you will get a lot more tolerance.

Cousins: Yes, if you go to a greenhouse, you expect it to be hot and humid because that is what plants need.

Michalski: It would be rather pathetic if, at a moment when human comfort standards are relaxing or getting broader and more sophisticated, the heritage business would stick to a narrowly defined temperature that was historically driven by human comfort. One hopes that given sustainability targets like energy and carbon savings, the conversation is not so much about humidity or seasonal adjustment—that is more about savings in nonpurpose buildings. Temperature seasonal setback is where the big savings will be. We do not want to be the obstacle to serious carbon footprint savings due to seasonal adjustments in average temperature. You may have heard that now temperature control is necessary because of its interaction with relative humidity. That plays out over periods of a few hours with the air mixing over and the fact that if the building buffers, it does so to RH rather than to dew point. Outside of a day there is no reason not to be playing with temperature adjustments for sustainability.

***Cousins to Michalski:** What about rate of change of temperature and humidity? Mechanical engineers are sometimes asked to control the rate of change in addition to the actual value.*

Michalski: Tracking down the history of where that mythology emerged is difficult. To a large extent it is exaggerated. When Marion Mecklenburg presented “the box” at the Boston Museum meeting [see Michalski, this volume] to 50 chiefs of conservation from across North America, much of the discussion was focused on issues about the rate of change. Marion would say to his facilities people, I want you to stay inside the box, how you ping pong around in there is up to you. The good news is that they tend to ping pong around one side of the box in one season. To turn it around and have someone say, “We can’t do that; we are going to bounce around day by day—is that bad?” Within the kinds of boxes we are talking about, the answer is no. To the extent that I have tried modeling, I have not found any plausible stress gradients that would emerge. The classic argument is that there is a gradient through the object; it has thermal inertia or humidity inertia so that those gradients lead to internal stresses.

Reilly: That was the mechanical answer; the chemical answer is that there is no penalty in terms of the rate of spontaneous chemical decay, mostly hydrolytic oxidative reactions, from moving from one temperature and moisture content condition to another. What changes is the rate of reaction. Precisely, there’s no *extra* penalty just from changing from one condition to another. Every condition has a rate associated with it. We’ve proven through experimentation that what matters is the way the rates all integrate. It is unlike mechanical damage where there could be a plausible mechanism of deterioration that is related to the rate of moisture content change. On the chemical side it’s better to be colder because it slows things, and it’s better to withdraw moisture (but not get too dry due to physical or mechanical concerns), but basically, you can move around as much as you want and what will matter is how much time the object spent at each condition. Each condition has a rate, and if you properly integrate those rates, then you can come up with an overall effective rate of decay or rate of preservation.

The pharmaceutical industry does something similar with mean kinetic temperature. That is how it ensures drugs are not ineffective by the time you get them because somebody stored them at too high a temperature. It must be 25°C or less; if it gets to 30°C, your pharmaceutical is compromised. If the concern is chemical decay, you can move around in temperature and achieve sustainable savings that way. One underused sustainable method is duty cycling. Having the same temperature and humidity 24 hours/day, all year long, is not effective or sustainable.

Michalski: What about loans determining guidelines? The ASHRAE guidelines say the set point can be the historic average for your collection but notes that many lenders will require AA conditions centered on 70/50, so to meet contractual obligations, you will need a special exhibits room. Part of the reason I participate in panels like this is because whatever the Smithsonian settles on is going to trickle down—what credible organizations do sets precedent. (And this field is about precedents that get encrusted.) It is better to be at the beginning of those precedents and steer them in a good direction than to wait and deconstruct them. It takes longer to deconstruct a myth than to be there and give birth to the right story. If we can get the international community (like Bizot) to change the specification, that has huge trickle-down effect. The single most stringent requirement for museum projects is not for their own collections—it is about contractual obligations and wanting to be on the loan circuit. This spans mega museums to small house museums. The extent to which we can get fundamental restrictions from the world of international loans to go in the same direction we are trying to go will have a huge effect on architectural projects.

Waller: Rates of change of temperature and humidity within a box probably don't affect many collections; however, we can't say categorically that they don't affect anything. For example, mineral collections are the most vulnerable of all, and certain opal specimens are extremely vulnerable to crazing. So there are always exceptions, and we can improve communications between conservation science, collection care, and facilities by encouraging collection care professionals to identify the most vulnerable objects to any particular issue and work with conservation science to get an idea of how susceptible they are.

Henry: This panel has been about collaboration. Ashley-Smith talked about empowerment, and we have talked about decision making.

Henry to the audience: How many of you feel that you are basically empowered, or have some fundamental knowledge to move forward on a different path rather than saying, "I want 70/50"?

[There was a sweeping show of hands across the audience.]

Moderator's Summary

We started this conversation highlighting the importance of respect, trust, and relationships between the varied professionals involved in the preservation of collections. Today, we are fortunate because each professional discipline at the table recognizes the importance of the others in order to optimize climate control for preservation environments. There are already strong

relationships built upon years of mutual respect and trust. What we all hope is that the exchange of dialogue here will be useful for each of you at your own institution. At the very least, we hope that by introducing you to the challenges of the interdisciplinary communication between the sciences, humanities, and business, you will be better equipped to foster collaboration to preserve your collections at your institutions.

Guides and Resources

A Guide to Discussions and Exercises Regarding the Preservation Environment: Determining and Implementing Your Institution's Optimal and Sustainable Preservation Environment

Following the symposium, the group of organizers held a debriefing session on content, lessons learned, and where to go from there. In presenting proceedings of the symposium, the organizers wanted to provide tools to encourage and guide readers on how to take the next steps toward improving sustainable environments for their own and other museums, libraries, and archives. Toward this end, this guide offers ideas for exercises and meetings with suggested content that can be adapted and further applied to various types of collecting organizations.

The authors encourage using this guide among a wide audience of required stakeholders and hope to encourage further open dialogue among collections managers, conservators, curators, facilities and operation staff, directors, and board members, as well as architects, engineers, vendors, and other contributors. It is through these dialogues that institutions can resolve often complex challenges and advance toward more sustainable solutions for collections preservation.

How to Use This Guide

This section provides both instructional and pedagogical guidance as well as subject content. Examples of pedagogical approaches are presented with sample subject content. Depending on the needs and desires of each user, the subject content can be exchanged for other content drawn from the suggested List of Questions presented below or from other sources. In an effort to help guide readers toward a sustainable environmental policy for collections preservation, the List of Questions follows a general order of steps that can be taken toward that goal.

Guided Discussions

Overview

Guided discussions are frequently utilized as an instructional method, and a more detailed description is given by K. Ellenberg.¹ This method works best with a facilitator. Your group may know of a good facilitator, or you may prefer to identify a professional facilitator. Facilitator resources are provided by the International Association of Facilitators.²

The Basics

- Decide on who should attend the discussion; include representatives from each stakeholder and area of expertise such as administration, collections, and facilities. Consider consulting experts such as architects, engineers, and conservators as appropriate.
- Identify an effective facilitator.
- Preselect questions for a guided discussion. (See List of Questions.)
- Use effective facilitation tools to encourage open and balanced discussion.
- Capture outcomes by scribing on a board or projecting outcomes on a screen.
- Discuss the next steps such as topics for future meetings, tasks or homework, group exercises (see Exercises below), drafting new policies or procedures, etc.

Discussion Format Variations

To keep things interesting and foster collaboration, one of several facilitation techniques can be used. A couple of formats are noted here for basic guidance, although many approaches are available. An experienced facilitator will know how to design meetings to best fit the subject matter and group participants.

Facilitation Model: 2, 4, 8, All

The facilitator divides the group into teams of two and either starts each team with a different question or starts everyone with the same question. After a few minutes, participants combine into teams of four for a few more minutes of discussion (Figure 1); then teams combine into



Photographs by Michael Barnes, Smithsonian Institution.

FIGURE 1. Smithsonian Institution staff participate in guided “2, 4, 8, All” discussions of the draft Declaration on the Collections Preservation Environment at Summit “Day Two” on March 22, 2013, at various locations through the Donald W. Reynolds Center for American Art and Portraiture and the Archives of American Art.

groups of eight participants for some additional minutes. Then the entire group holds a discussion while the facilitator scribes the outcomes on a board or projection screen.

Facilitation Model: The Book Club

The book club discussion format may use a facilitator but may also work well without a single group leader. This discussion model is described in more detail on several websites, including that of the American Library Association.³

- Prepare in advance by selecting questions. (See List of Questions.)
- Write each question on an index card.
- Convene a meeting of about one-hour duration.
- Review basic meeting rules such as no interruptions, keep to the question topic, table off topics to return to later, avoid refuting ideas, etc. (Refer to more detailed guidelines online.)
- If there is not a single facilitator, assign a scribe (optional), assign a timer (optional), pass around index cards with questions written on them, and ask each person to present a question in turn.

Exercises

Group exercises are intended to encourage interaction. In some cases learning to work as a team is just as important as the specified outcomes of the exercise. Learning to view common concerns from another's perspective is key in problem solving for complex issues such as sustainable environments in museums. A few sample exercises are offered, although the team may wish to design their own exercises with guidance from the List of Questions below.

Group Exercise: Touring Facilities

Take turns touring each other's departments, emphasizing environmental and sustainable needs or impacts for each building area. For instance, tour a storage area and describe the environment, equipment, type of materials, access, fire suppression, pest management, and other details, or walk through a mechanical room that serves a collection space and review the system features. Set aside a couple hours each week or month for one departmental tour. Include departmental participants from collections management, curation, conservation, and facilities operations. During each tour, department representatives can discuss how they are integrating or planning on implementing increased sustainable solutions to their day-to-day activities.

Anticipated outcomes are that various specialists will understand perspectives, goals, and constraints of other departments. For example, collections managers, conservators, curators, and security staff will have a better understanding of how environmental mechanical systems work and are adjusted and maintained, what system restraints are, or how monitoring is achieved; facilities staff may better understand collections preservation concerns and how preservation risks are identified through looking at actual materials; curators, conservators, collections managers, and facilities staff may better understand concerns and operations for security.

Following each tour, the group may decide to distribute evaluation sheets and collect information such as the answers to the following questions:

- What information was new to you?
- What areas of concerns and/or expertise overlap?
- What opportunities exist for further collaboration and finding new solutions for improved sustainability?

Group Exercise: Sketching Climate Zones

After a tour of the building, ask participants to identify and sketch out separate climate zones in the building. This exercise can be done in teams of two. Pairing participants from different departments together enhances the experience. Post the sketches on a wall and have each group of mixed professionals present their sketches.

Group Exercise: Sketching Mechanical Systems

Following a facilities tour and/or presentation with drawings and discussions, request participants make their own sketch of the building's mechanical systems. For larger institutions, participants can break into teams, and each team can be assigned a separate building wing or climate zone. Post the sketches on a wall, and have each group of mixed professionals present their sketches.

Group Exercise: Designing an Environmental Collections Risk Assessment

Set up teams of two to four participants. Each team can have representatives from different departments. Ask each team to design a risk assessment for collections preservation. The focus of the risk assessment should be on the effects of the environment on collections. Have teams present their approaches to the group as a whole.

List of Questions

The following list of questions is organized into sections that reflect a stepped approach that can serve as a guide to institutions in developing a sustainable environmental policy for collections preservation and the museum as a whole.

Building the Team

1. Combining the expertise of stakeholders is an important theme for several of the authors of this book. Waller describes the stakeholders as being, at the least, the facilities engineer, the conservation scientist, and the conservator. When you consider your library, archive, or museum, who would you add to the list as a stakeholder? What role does each stakeholder have in establishing and maintaining the preservation environment? Who has the final say and why?
2. Who should be involved in making decisions about the environment for collections?
3. Who needs to be involved in decision making for the collections environment? What outside expertise needs to be brought in?

Clarifying the Why

4. What is the main reason collecting institutions are looking toward more sustainable approaches for collections preservation?
5. Why is it important to preserve collections? Should all collections be preserved?
6. Why is it important for the Smithsonian to reconsider environmental standards for its collections?
7. How can long-term preservation of collections best be achieved while being energy conscious?
8. What types of collections are most susceptible to environmental changes?
9. How does the environment affect preservation of collections?
10. How have environmental standards changed in the last century?
11. How have current standards evolved?
12. What myths and realities exist in the collections world about environmental controls for art preservation?
13. What were environmental standards for collections based on?
14. How can the Smithsonian be the best leader in environmental controls for collections preservation? What decisions will the Smithsonian make that will trickle down to other museums? What can the Smithsonian learn from other institutions?

Gathering Information

15. The architect or mechanical engineer comes to you and asks what target set points you want for your collection. How do you respond?
16. A small historic house museum has almost no budget and is run primarily by volunteers. How does staff go about improving the environment for their collections while still keeping energy costs to a minimum?
17. A large institution like the Smithsonian has the resources to study and improve environmental controls; how does a small museum with only 2.5 full-time employees achieve the same museum best practices when it comes to environmental controls for its collections? The small museum would like the same energy cost savings while still preserving its collections.
18. What steps should be undertaken in determining appropriate environments for collections?
19. How much time will it take to gather the information you need? Should you bring in outside experts? How do you determine which experts are the most appropriate for your institution?
20. What additional information do you need regarding the materials that you preserve in your collections? Some collection types are robust and can tolerate a wide range of temperatures, others are vulnerable to subtle changes, and still others are yet unstudied for their long-term preservation. What areas of research would you like to see pursued within your organization or at conservation research centers to help understand the role of the environment in the preservation of objects?
21. Many of the essays discuss the history of preservation science and the establishment of guidelines for temperature and humidity set points for exhibition and storage of collections. For

instance, where does the guidance that museums should keep their collections in a tightly controlled environment of 70°F (22°C)/50% RH come from? What did you learn about the history of this discussion that surprised you? Did you understand historic guidelines to be a “standard”? What is the difference between guidelines and standards? What guidelines or standards have you used with your collections? What guidelines are currently available?

22. When you consider the life cycle management of the systems that provide heating, cooling, and ventilation, what areas would you like to know more about? Reilly describes walking through mechanical rooms with facilities engineers and collections managers; what activities could you do with the stakeholders that would provide a basis for further discussion and collaboration and that would meaningfully contribute to the preservation of collections? What activities might meaningfully contribute to sustainable use of energy or energy savings?
23. What environmental monitoring exists in your institution? What environmental monitoring would be needed to determine more sustainable methods for environmental controls? How would you go about assessing the current systems and determining whether you need additional or less monitoring for newer climate strategies?
24. How will the climate affect human comfort?
25. How will the climate affect the original or existing fabric of historic buildings?
26. How will you provide funding for assessment, planning, and implementation?
27. What are different methods for conducting risk assessments?
28. What are the premises and limits of model structure, such as a risk model?
29. In assessing collections risks, what risks are used in determining environmental target set points?
30. What is ASHRAE? How was chapter 23 of the ASHRAE handbook developed? Who wrote it?
31. What is CPRAM, and how does it work?
32. Define *source*, *path*, and *effect*, and how they are used.
33. How can you assess what a building is passively capable of without introducing a dramatic temporary change in environment?
34. How can environmental controls be best utilized without further damaging the fabric of a historic building?
35. What are some passive or nonmechanical strategies that can be explored for controlling environments?
36. What is the WUFI computer model, and how effective can it be for museums?
37. What is PAS 198?
38. What is the best environment for your museum? How does one arrive at that?
39. What is EGOR, and what was its significance on changing environmental standards?
40. How long do the steps take in determining appropriate target set points?

Drafting a Plan

41. Many organizations that preserve cultural heritage have a mission statement and policy documents such as a preservation plan. Does your organization have a preservation plan that explicitly addresses temperature, humidity, and air quality and their role in preservation?

What would you do to add, refine, or upgrade your statement on the role of the preservation environment for your collections?

42. What steps are required for moving toward a more sustainable environmental plan?
43. What are the priorities of these steps?
44. How can these steps fit into a schedule?
45. How can the steps be funded?

Implementing a Plan

46. Who or what team will be responsible for carrying out these steps?
47. What follow-up mechanisms need to be in place to ensure steps are completed?

Evaluation

48. How should the planning and implementation phases be evaluated and adaptations made?

Notes

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2. International Association of Facilitators website, <https://www.iaf-world.org> (accessed September 16, 2015).
3. American Library Association, "Book Discussion Groups," <http://www.ala.org/tools/atoz/book-discussion-grps> (accessed September 16, 2015).

Resources and References

Key Informational Resources

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- American Institute for Conservation of Art and Historic Works Collections Care Network. <http://www.conservators-converse.org/publications-resources/collection-care#CCN> and https://netforum.avectra.com/web/DynamicPage.aspx?Site=AICHAW&Webcode=LeadershipDetail&cmt_key=2205560c-2a9c-449a-a7e0-27028e608578 (accessed September 16, 2015).
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- International Institute for Conservation of Historic and Artistic Works and International Council of Museums Committee for Conservation. 2014. Environmental Guidelines: IIC and ICOM-CC Declaration. <https://www.iiconservation.org/node/5168> (accessed September 16, 2015).
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Seminal Publications

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- Kirby Atkinson, Jo. 2014. Environmental Conditions for the Safeguarding of Collections: A Background to the Current Debate on the Control of Relative Humidity and Temperature. *Studies in Conservation*, 59(4):205–212. <http://dx.doi.org/10.1179/2047058414Y.0000000141>.

Staniforth, Sarah. 2014. Environmental Conditions for the Safeguarding of Collections: Future Trends. *Studies in Conservation*, 59(4):213–217. <http://dx.doi.org/10.1179/2047058414Y.0000000142>.

Related Publications

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Summit on the Museum Preservation Environment Program



SUMMIT on the
MUSEUM PRESERVATION ENVIRONMENT
March 5, 2013 | National Museum of the American Indian
Rasmuson Theater

Program

- | | |
|---------------------------|---|
| 9–9:05 a.m. | Welcome |
| Speaker: | Bill Tompkins, Director, National Collections Program |
| 9:05–9:20 a.m. | Introduction to the Summit |
| Speaker: | Scott Miller, Deputy Under Secretary for Collections and Interdisciplinary Support |
| 9:20–10 a.m. | History of Environmental Management in Museums: Evolution of Theory and Practice |
| Speaker: | Stefan Michalski, Senior Conservation Scientist, Canadian Conservation Institute |
| | Introduction by: Robert Koestler, Director, Museum Conservation Institute |
| 10–10:45 a.m. | Risk Assessment and Assignment of Environment Parameters |
| Speaker: | R. Robert Waller, PhD, CAPC, FIIC, President and Senior Risk Analyst, Protect Heritage Corp. |
| | Introduction by: Bill Tompkins, Director, National Collections Program |
| 10:45–11:15 a.m. | Break |
| 11:15 a.m.–12 p.m. | Conservation Environments, Museum Buildings, and Sustainability |
| Speaker: | Michael C. Henry, PE, AIA, Watson & Henry Associates/University of Pennsylvania |
| | Introduction by: Sharon Park, Associate Director, Architectural History and Historic Preservation |
| 12–1:15 p.m. | Lunch (on your own) |
| 1:15–1:20 p.m. | Introduction to the Afternoon |
| Speaker: | Bill Tompkins, Director, National Collections Program |

1:20–2:05 p.m.	Standards and Best Practices, Part I: Choosing Standards and Best Practices
Speaker:	Jim Reilly, Director, Image Permanence Institute
Introduction by:	Sarah Stauderman, Collections Care Manager, Smithsonian Institution Archives
2:05–2:50 p.m.	Standards and Best Practices, Part II: British Publicly Available Specification 198, “Specification for managing environmental conditions for cultural collections”
Speaker:	Dr. Jonathan Ashley-Smith, Independent teacher and consultant (formerly Head of Conservation, Victoria and Albert Museum)
Introduction by:	Catharine Hawks, Conservator, National Museum of Natural History
2:50–3:15 p.m.	Break
3:15–4 p.m.	Sustainability: Climate for Culture
Speaker:	Fiona Cousins, PE, LEED AP BD+C, Principal, Arup
Introduction by:	David Hauk, Supervisory Electrical Engineer, Energy Management, Office of Facilities Management and Reliability
4–4:45 p.m.	Panel Relationships, Respect, and Trust: Collaboration among Museum and Facility Professionals
Moderator:	Cecily Grzywacz, Facilities Scientist, National Gallery of Art
Panelists:	Stefan Michalski, R. Robert Waller, Michael C. Henry, James Reilly, Jonathan Ashley-Smith, and Fiona Cousins
4:45–5:15 p.m.	Smithsonian Institution Collections Space Prototypes: Project and Principles
Speaker:	Luanne Greene, Principal, Ayers/Saint/Gross
Introduction by:	Ann Trowbridge, Associate Director for Planning, Office of Planning and Project Management
5:15–5:30 p.m.	Concluding Remarks
Speaker:	Kendra Gastright, Director, Office of Facilities Management and Reliability
5:30–7 p.m.	Reception–Potomac Atrium

Summit Day Two Program

Donald W. Reynolds Center for American Art and Portraiture, Nan Tucker McEvoy Auditorium

March 6, 2013

8:30 a.m. **Summit Check-in Begins**

9–9:05 a.m. **Introduction to the Day**

Speaker: Bill Tompkins, Director, National Collections Program

9:05–9:20 a.m. **Welcome: Secretary Clough**

9:20–10 a.m. **Overview of Proposed Smithsonian Institution Declaration on the Museum Preservation Environment**

Speaker: Sarah Stauderman, Collections Care Manager, Smithsonian Institution Archives

10 a.m.–12 p.m. **Smithsonian Institution Tools and Models for Successful Collaboration**

What Smithsonian tools exist to assist the museum and facilities professionals achieve and maintain the desired outcome of an established environment?

Moderator: Michael Carrancho, Associate Director, Office of Engineering Design and Construction

- SI Explorer and Collections Space Database (Paul Drake, Technical Services Division of OEDC)
- OFMR/System Engineering Division monitoring reports and automated systems (Paul Tintle, System Engineering Division of OFMR)
- Museum Conservation Institute services and specialized equipment (Paula DePriest, Museum Conservation Institute)

10:45–11 a.m. **Break**

What models exist at the Smithsonian that highlight collaborative work for establishing environment in exhibition space design and preparation, and new long-term storage spaces?

- Case Study: Reynolds Center (Andy Smith, Zone Manager, OFMR)
- Case Study: Leased Facilities (Kendra Gastright, Director, OFMR)

Panel Discussion: Paul Drake, Paul Tintle, Paula DePriest, Andy Smith, Kendra Gastright

12–1 p.m. **Lunch (on your own) Break-out Session Rooms**

1–3 p.m. **Break-Out Working Sessions**

During the breakout sessions, Smithsonian staff committed to vetting the declaration document in each of these subject areas will be asked to review and comment on the same questions, which will be reported out in the facilitated discussion at 3:15 p.m. All registered stakeholders will get a copy of the draft declaration prior to the Summit and will be asked to pre-select their break out session of choice.

Concurrent Working Sessions	Roles	Room Location
Environment and Collections Preservation	Leaders: Sarah Stauderman, SIA, and Kathy Makos, OSHEM OP&A Facilitator: James Smith Note-taker: Mary Ballard, MCI	MacMillan Education Center (1 st floor)
Collaboration with Diverse Professional Specialists	Leader: Michael Carrancho, OFEO OP&A Facilitator: Ioana Munteanu Note-taker: Jennifer Giaccai, MCI	McEvoy Auditorium
Monitoring, Data Collection, and Data Interpretation	Leader: Paul Tintle, OFEO OP&A Facilitator: Kathy Ernst Note-taker: Hanna Szczepanowska, MCI	Auditorium Lobby
Risk Management	Leader: Cathy Hawks, NMNH OP&A Facilitator: Claire Eckert Note-taker: Nicole Little, MCI	Kogod Courtyard
Performance Specifications	Leader: David Hauk, OFEO OP&A Facilitator: Whitney Watriss Note-taker: Carol Grissom, MCI	Victor Building, Suite 2200 Conference Room

3–3:15 p.m.

Break

McEvoy Auditorium

3:15–4:30 p.m.

Working Session Report Outs by Group Leaders

1. Responses to Proposed Smithsonian Institution Declaration on the Museum Preservation Environment
2. Participant Questions/Discussion

4:30–5 p.m.

Concluding Remarks

Speakers:

Nancy Bechtol, Director, Office of Facilities Engineering and Operations

Scott Miller, Deputy Under Secretary for Collections and Interdisciplinary Support



Smithsonian Institution

Declaration on the Collections Preservation Environment

Introduction

With this Declaration on the Collections Preservation Environment, the Smithsonian Institution clarifies values, shared by the diverse professional disciplines that directly and indirectly care for Smithsonian collections, related to the collections preservation environment and likewise presents a shared vision for implementing environmental policy based on these common values.¹ Collections stewardship is a key component and core priority of the Smithsonian's Strategic Plan. Assembled over the course of 168 years, Smithsonian collections are fundamental to carrying out the Institution's mission, serving as the intellectual foundation for scholarship, discovery, exhibition, and education. Smithsonian collections represent a diverse range of materials and disciplines, including works of art, historical artifacts, natural and physical science specimens, living animals and plants, images, archives, library volumes, audio and visual media, digital art and time-based media, and their associated information. Together, these irreplaceable national icons, examples of everyday life, and scientific material preserve the past, increase our understanding of society and the natural world in which we live, and support the research that expands human knowledge in the arts, humanities, and sciences. The scope, depth, and unparalleled quality of these collections make it imperative to ensure that they are properly preserved and made accessible for current and future generations to enjoy and study.

Environment and environmental control are fundamental components of collections preservation; appropriate environmental conditions provide collections with chemical, biological, and mechanical stability to extend their life, making them available to future generations. As described in the American Institute for Conservation's Guidelines for Practice, assigning appropriate environmental conditions extends the life of cultural property.² The Smithsonian Institution aims to provide and actively manage optimized environments to promote collections preservation based on a balance of scientific research, engineering capability, collections management protocols, and environmental impact. The dynamic factors comprising the preservation environment, to which the common values and shared vision statements detailed below apply equally, are (1) humidity and acceptable ranges for relative humidity, (2) temperature and acceptable ranges for temperature, and (3) air quality and ventilation.³

Common Values and Shared Vision

Core Area	Common Values	Shared Vision
Collaborating	<p>The Smithsonian Institution believes that collaboration is the foundation for establishing environmental parameters. Achieving optimal preservation environments requires defining objectives and finding consensus among all stakeholders. Agreement on environmental parameters is inherently challenging because it requires consideration of a number of factors, such as evolving material-specific environmental guidelines; building fabric, which may be of historic significance and fragile itself; system capability; limitations on staff and resources; and the growing impetus to reduce energy costs and operate more sustainably.</p>	<p>The Smithsonian Institution supports a workforce that collaborates across disciplines to establish, monitor, and maintain collections environments.</p> <p>Roles and responsibilities of all stakeholders across all core areas are clearly delineated. Responsibilities include how each stakeholder contributes to routine planned discussions.</p> <p>Architects, curators, conservators, collections specialists, energy managers, engineers, facility managers, scientists, industrial hygienists, IT specialists, administrators, exhibition specialists, and others are included in discussions of the establishment of collections environmental parameters.</p> <p>Decisions are made by sharing information, negotiating positions based on information, and developing consensus toward the expressed value of progress toward an optimized environment.</p> <p>Resources such as the National Collections Program and facility capital and maintenance planning are available to collaborators to foster the spirit and effect of collaboration.</p>
Monitoring	<p>The Smithsonian Institution recognizes monitoring as an essential element of preservation environment activities. Monitoring and the data derived from monitoring are the basis of conversations between stakeholders; they provide meaningful information for attempting diverse preservation management actions, such as establishing seasonal adjustments or rehousing priorities, and aid in the establishment of priorities for long-term improvements.</p>	<p>The Smithsonian Institution has a standard way in which environmental monitoring data are collected, reported, and interpreted across the organization.</p> <p>All collections spaces are designed and built with monitoring plans and protocols established and defined at the outset of design discussions.</p> <p>All collections spaces are designed and built with mechanisms for monitoring environmental conditions for the space and air handling systems.</p> <p>Environmental monitoring data are readily accessible to all stakeholders.</p> <p>Environmental monitoring of collections and exhibition spaces is automated and integrated.</p> <p>Existing systems and spaces are studied for action and modeling, especially in historic or older spaces that may not be compatible with desired specifications.</p> <p>The purchase of room- and system-level environmental monitoring equipment and associated software is reliably supported.</p>

Training	<p>Training provides the opportunity for understanding the evolution of theory and practice in the application of environmental parameters. The Smithsonian Institution believes that education and training of the Smithsonian workforce on the role of the environment in collections preservation, including promoting the understanding of the relationship between material damage in collections and exposure to an improper environment, is fundamental to effective collaboration.</p>	<p>The Smithsonian Institution is committed to cultivating professional development and training the workforce on the essential role that a controlled and optimized environment has on collections preservation, as well as on the theory and practice of the preservation environment and the variety of means that ensure collections have optimal environments.</p> <p>Likewise, Smithsonian employees commit to keeping current with the theory and practice of the preservation environment. It is incumbent on staff to take training to understand why reappraisal of established environmental parameters is part of the ongoing professionalism of collections care.</p>
Guidelines and Best Practices	<p>The Smithsonian Institution believes that standards, guidelines, and best practices for establishing, monitoring, and maintaining the collections environment form the basis for reasoned collections environment decisions and therefore does not support a single specification for all collections. A broad range of choices may be made with respect to relative humidity, temperature, and air quality to provide optimal preservation environments and to meet operational and energy sustainability goals.⁴ Smithsonian scientists are poised to play a role in the research that leads to establishing environmental parameters.</p>	<p>The Smithsonian Institution conducts research concerning the relationship between the environment and collections preservation in order to continue refining an understanding of the role of the preservation environment and the mechanisms for damage to collections.</p> <p>Standards are routinely reviewed, and continuing research contributes to the refinement of existing guidelines and best practices.</p> <p>Standards and regulations regarding fire safety, health, building envelope, and HVAC are well understood as part of the discussion of the preservation environment.</p>
Risk Management	<p>Some Smithsonian collections are tolerant of a wide range of environments because of their robust physical nature; other collections have specific requirements and special needs for long-term preservation. The Smithsonian recognizes that different approaches may be used to characterize the requirements of a particular collection or facility. Comprehensive risk management models used in collections management have an important role to play in establishing environmental parameters. Standards may be used in tandem with risk management models to develop reasoned collections environments.</p>	<p>Smithsonian Institution collections staff are trained to be knowledgeable about the profiles of the materials in their collections and apply modern approaches to categorizing collections' fragility and hardness.</p> <p>Environmental requirements for a collection are thoroughly discussed with stakeholders, and the methodologies used to make decisions, including the resulting decisions themselves, are well documented.</p> <p>Historic structures are considered when performing risk management exercises and are evaluated for building performance.</p>

(continued)

Sustainability	<p>The Smithsonian Institution acknowledges that the preservation environment, operational sustainability, and environmental sustainability are interdependent. More sustainable preservation environments and operations also may extend the lifetime of collections.</p> <p>Sustainable preventive conservation methods have the potential to influence the type of preservation environment required for collections.</p>	<p>Improving the sustainability of collections preservation environments requires implementing strategies to conserve energy and water and to ensure the continued operations of preservation environment systems. The Smithsonian pursues these strategies while also fulfilling its responsibility to preserve, and to make accessible to present and future generations, the collections in its care.</p> <p>Energy and water conservation measures that may affect the preservation environment are developed in collaboration with all stakeholders.</p> <p>The process for selecting systems utilized in the preservation environment takes into account life cycle costs impacting operational and financial sustainability.</p>
Customized Specifications	<p>The Smithsonian Institution considers the preservation environment of each collections space to be one of the paramount mechanisms for ensuring the longevity of collections. Therefore, the preservation environment specifications of each collections space are actively defined to meet practical and sustainable parameters. Because of the wide variety of collections materials and collections spaces across the Smithsonian and because conservation research has acknowledged the variety of approaches to establishing preservation environment parameters, there is not a default preservation environment specification. The space may be intentionally unconditioned or may be continually refined on the basis of new data through a collaborative process among stakeholders, but tightly controlled 70°F/50% RH is no longer considered an appropriate, practical, sustainable, or useful set point for all collections.⁵</p>	<p>The Smithsonian captures the many data points of the preservation environment, allowing stakeholders to discuss it flexibly and openly, to adapt to changing information, and to account for differences of findings on environmental readings.</p> <p>At a minimum, all collections spaces receive proactive specification of relative humidity and temperature allowances and seasonal adjustments.</p> <p>Several core areas from this document—monitoring, guidelines and best practices, risk management, and sustainability—are factors that contribute to the collaborative establishment of the optimal preservation environment for each collections space.</p>

Notes

1. Participants in the Summit on the Museum Preservation Environment held in Washington, D.C., in March 2013 affirmed the goals of this declaration in a straw poll after discussion and review of presentations by experts in the fields of preservation, facilities management, and sustainability.
2. Guidelines for Practice of the American Institute for Conservation of Historic and Artistic Works, Section 20, “Preventive Conservation,” <http://www.conservation-us.org/about-us/core-documents/code-of-ethics-and-guidelines-for-practice/code-of-ethics-and-guidelines-for-practice#.VpPq3lL0-rg> (accessed January 11, 2016).
3. Environmental factors such as light and integrated pest management, which have an interrelated role in the preservation environment, will be specifically addressed in separate policy statements.
4. Several guidelines and standards are especially valued for their helpfulness in formulating a rationale for the specification of relative humidity and temperature for collections:

- British Standards Institute, PAS 198:2012, Specification for Managing Environmental Conditions for Cultural Collections (London: British Standards Institute, 2012).
 - American Society for Heating and Air-Conditioning Engineers (ASHRAE), “Museums, Galleries, Archives, and Libraries,” in *ASHRAE Handbook: Heating, Ventilating and Air-Conditioning: Applications* (Atlanta, GA: ASHRAE), 23.1–23.22.
 - Smithsonian Institution Facility Design Standards, http://www.ofeo.si.edu/ae_center/pdf/SI%20Standards_Jan2012.pdf (accessed June 6, 2014).
 - American Institute for Conservation of Historic and Artistic Works, Interim Guidelines for Loans, http://www.conservation-wiki.com/wiki/Environmental_Guidelines (accessed June 19, 2014).
 - Smithsonian Institution, Smithsonian Directive 600, Collections Management, <https://www.si.edu/content/pdf/about/sd/SD600andAppendix.pdf> (accessed January 11, 2016).
5. In recent years, the Smithsonian Institution has actively pursued specifications that reflect seasonal adjustments, setbacks, and shutdowns calculated to avoid condensation in building envelopes. Research by the Smithsonian Institution Museum Conservation Institute demonstrated that a broad RH range can be tolerated by many objects. For exhibition spaces where the need for human comfort and protection of building structures is frequently cited, a guideline of 37%–53% RH and 66°F–74°F has been developed. See Marion F. Mecklenburg, *Determining the Acceptable Ranges of Relative Humidity and Temperature in Museums and Galleries: Part 1, Structural Response to Relative Humidity* (Washington, D.C.: Smithsonian Museum Conservation Institute), <http://www.si.edu/mci/downloads/reports/mecklenburg-part1-RH.pdf> (accessed June 6, 2014). Many spaces for collections at SI have adopted a “cooler and drier” methodology as well.

Contributors

Jonathan Ashley-Smith is an independent teacher, researcher, and consultant and former head of conservation at the Victoria and Albert Museum. He studied chemistry to postdoctoral level at the University of Bristol and University of Cambridge. He joined the Victoria and Albert Museum (V&A), London, in 1973 as scientist and trainee conservator. Between 1977 and 2002 he was head of conservation at the V&A. Between 1988 and 2010 he was actively involved with the Royal College of Art (RCA)/V&A postgraduate program of training and research. He was visiting professor at the RCA between 2000 and 2010. In 2000 he was awarded the Plowden Medal for his contribution to the conservation profession. He was secretary-general of the International Institute for Conservation from 2003 to 2006. In 1994 he was awarded a Leverhulme Fellowship to study risk methodologies, resulting in the book *Risk Assessment for Object Conservation*, published in 1999. He has run risk assessment workshops for students and professionals throughout Europe. He has supervised research students at a number of UK universities on projects relating to risk, ethics, and ethnography. He has written about the relevance of environmental standards and controls. “Let’s Be Honest—Realistic Environmental Parameters for Loaned Objects” (*Studies in Conservation*, 1994) is still required reading. He is currently a “work package leader” within the European Commission–funded research project “Climate for Culture,” in which his major preoccupation is the search for damage functions that might help predict risks for collections in historic buildings whose environments may be affected by climate change. He recently co-organized the international conference “Climate for Collections: Standards and Uncertainties” with the Doerner Institut in Munich, Germany.

Nancy Bechtol, the Smithsonian’s director of the Office of Facilities Engineering and Operations (OFEO), leads the largest unit at the Smithsonian with a staff of 1,900 who are responsible for facilities planning, programming, real estate, and architectural history and preservation; engineering, design, construction, and cost estimating; security, maintenance, operations, and horticulture; and safety, health, and environmental management. OFEO performs these centralized facilities services to 12 million square feet of space, including 19 museums, 9 research centers, and the National Zoo located in Washington, D.C., six states throughout the country, Panama, and Chile. She oversees a budget of over \$175 million in capital funding and over \$185 million in operations and maintenance. Prior to her role as the director of OFEO, she was the director of the Office of Facilities Management and Reliability at the Smithsonian Institution from 2001 to 2012. She managed all facilities management utilizing an in-house workforce of over 850 and an operating budget of \$100 million. She was also responsible for overseeing the exhibition quality gardens that surround the museums. She graduated from the University of Maryland in 1980 with a bachelor of science degree in horticulture. She received her master’s

degree in 1984 from the University of Delaware through the Longwood Program in Public Garden Administration. In 2007, she became a certified facility manager through the International Facility Management Association.

G. Wayne Clough (pronounced “cluff”) was the twelfth secretary of the Smithsonian Institution, the world’s largest museum and research complex. The Smithsonian includes 19 museums and galleries, 20 libraries, the National Zoo, and 9 research centers and has activities in nearly 100 countries. Since becoming secretary in July 2008, he has taken the Smithsonian in new directions. A comprehensive strategic plan—the first of its kind for the Smithsonian—creates a new framework for goals, enterprises, and operations. The Smithsonian focus is on four grand challenges: Unlocking the Mysteries of the Universe, Understanding and Sustaining a Biodiverse Planet, Valuing World Cultures, and Understanding the American Experience. Complementing the grand challenges is a goal to use digital technology to engage all Americans. He is responsible for an annual budget of \$1 billion and about 6,000 employees. As a federal trust, the Smithsonian receives about 65% of its funding from the federal government and generates funding from contributions and business activities such as museum shops. Since he became secretary, more than 350 exhibitions have opened across the Smithsonian. He has overseen the opening of major permanent exhibitions, including the *Star-Spangled Banner* at the National Museum of American History, the Hall of Human Origins at the National Museum of Natural History, the new wing at the National Air and Space Museum’s Udvar-Hazy Center, and Asia Trails at the National Zoo. Before his appointment to the Smithsonian, he was president of the Georgia Institute of Technology for 14 years. He received his bachelor’s and master’s degrees in civil engineering from Georgia Tech in 1964 and 1965 and a doctorate in 1969 in civil engineering from the University of California, Berkeley. He was a member of the faculty at Duke University, Stanford University, and Virginia Tech. He served as head of the department of civil engineering and dean of the College of Engineering at Virginia Tech and as provost at the University of Washington. He is the recipient of eight honorary doctorates.

Fiona Cousins, PE, LEED AP BD+C, principal, Arup, leads the sustainability team in the New York office of Arup, is one of the leaders of the mechanical engineering team, directs technical investments for Arup’s Americas Region, and is a member of the Arup Americas Board. She has a background as a mechanical engineer and has spent much of her career engaged in HVAC design, with an area of specialization in thermal comfort and energy efficiency. She developed a strong interest in sustainability during the 1990s and has been working since then to incorporate sustainability into her projects. The other major strand of her professional career has been interdisciplinary design and integration, and she is most interested in complex projects in which collaboration between disciplines can achieve breakthrough results. She has been a LEED accredited professional since 2001 and has served as both manager and director for a number of projects that are pursuing the highest levels of LEED goals. She also served for two years as the chair of the New York Chapter of the U.S. Green Building Council (Urban Green).

She is currently chair-elect of the board of the U.S. Green Building Council. A frequent presenter on transformative sustainable building design, she has presented technical papers in the areas of low-energy design and sustainability.

Cecily Grzywacz is a facilities scientist in the AFM–Sustainability Office of the Facilities Management Division at the National Gallery of Art (NGA). She is a liaison between conservation, science, and facilities and considers herself a voice for the collection within Facilities. She works closely with the engineers to ensure that operation and maintenance and AFM projects continue to provide preservation environments for NGA collections. Previously, she worked at the Getty Conservation Institute of the J. Paul Getty Trust from 1985 until 2010 as a research scientist. She developed protocols that reduced energy consumption while maintaining a preservation environment at the Getty Center Museum and conducted research to understand the deterioration of cultural heritage. She is a senior research scientist with nearly 30 years of professional experience in environmental monitoring and analytical chemistry, specializing in the study of the potential risk of pollutants to cultural heritage, especially for preservation microclimates and the evaluation of air monitoring technologies and passive sampling devices. In 2006, she authored the book *Monitoring for Gaseous Pollutants in Museum Environments*, a summation of her experience of air quality monitoring for both outdoor and indoor-generated pollutants. She is a frequent guest lecturer in preventive conservation. Since 2003, she has been a primary reviewer of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) applications handbook chapter “Museums, Galleries, Archives, and Libraries”—a guideline for designing, heating, ventilation, and air-conditioning systems. In 2010, she received the ASHRAE Distinguished Service Award.

Michael Henry, PE, AIA, is principal engineer/architect with Watson & Henry Associates. For the past 30 years, he has specialized, nationally and internationally, in the preservation of historic buildings, in engineered stabilization of large artifacts, and in analysis and design of environments for cultural heritage collections. He is a registered profession engineer in New Jersey and several other states and is a registered architect in New Jersey. He received a bachelor of science in mechanical engineering from the University of Houston and a master of science in engineering from the University of Pennsylvania. He is adjunct professor of architecture in the graduate program in historic preservation at the University of Pennsylvania and is a guest lecturer and independent study supervisor for the graduate program in art conservation at the University of Delaware/Winterthur. From 2005 to 2009, he taught sustainable strategies at the Centre for Sustainable Heritage at University College London, UK. In 2006, he received a Fulbright Distinguished Scholar award to teach and research on the topic of low-energy collections environments in historic buildings. He has been an instructor and consultant for the Getty Conservation Institute in North Africa and Latin America. His recent environmental management projects and consultations range from Ernest Hemingway’s Finca Vigía near Havana, Cuba, to the renovations of the subterranean archives at the Harriett Beecher Stowe Center in Hartford, Connecticut.

Stefan Michalski is a senior conservation scientist at the Canadian Conservation Institute (CCI). In 1989, he developed the CCI light damage slide rule, which was recently replaced by a light damage calculator on the CCI website. He provided all the colorant sensitivity tables used in publications on museum lighting from both the CIE and the Illuminating Engineers Society of North America. In 1993 he published the article “Relative Humidity: A Discussion of Correct and Incorrect Values,” which was recently selected for a book of selected historical readings in preventive conservation. In 1994, he coined the “nine agents of deterioration and stages of control” and initiated the CCI poster “Framework for Preservation of Museum Collections.” In 1999, he authored the section on humidity and temperature specifications in the “Museums, Libraries, and Archives” chapter of the ASHRAE handbook. In 2000, he authored the CCI *Guidelines for Humidity and Temperature for Canadian Archives*. Between 2003 and the present, in partnership with the International Centre for the Study of the Preservation and Restoration of Cultural Property and Instituut Collectie Nederland, he developed and taught at the three-week course “Reducing Risks to Collections,” which has been held in Ottawa, Rome, Sibiu, Beijing, Quito, and Istanbul. Currently, he is finalizing a manual and a software tool for the risk assessment method developed during that partnership and now used by CCI in its risk assessments. In 2005, at the invitation of the International Council of Museums and the UN Educational, Scientific and Cultural Organization, he wrote the “Collection Preservation” chapter in *Running a Museum: A Practical Handbook*, available now in five languages. Also in 2005, he received the Harley J. McKee Award from the Association for Preservation Technology International, given to “individuals who have made outstanding contributions to the field of preservation technology.” This award was primarily for work on minimizing humidity risks to the frequent combination of collections plus historic building. He was on the steering committee, as well as a contributing writer, for the British Standards document called PAS 198, published in 2012. His primary foci now are two projects: a computerized prediction model for crack risk in a varied collection and a book on the museum environment to be coauthored with Jim Druzik of the Getty Conservation Institute.

Scott Miller, deputy undersecretary for collections and interdisciplinary support at the Smithsonian Institution, serves as the principal advisor to the Institution’s senior staff on the central planning and development of collections and interdisciplinary support operations, including collections management, conservation and preservation, and related functions. On matters of collections management, he serves as a liaison between the Smithsonian and various commissions, advisory boards, federal agencies, foreign governments, and private and professional cultural and scientific organizations in the United States and around the world, fostering cooperative programs and promoting the Institution’s programs. He previously served as deputy under secretary for science, helping oversee the Smithsonian’s science museums and research facilities, major research initiatives, collections management, exhibitions, and educational programs. From 2004 to 2006, he was the associate director for science at the National Zoological Park, spearheading the rehabilitation of the Conservation and Research Center in Front Royal,

Virginia. From 2000 to 2006, he was chairman of the departments of entomology and systematic biology at the National Museum of Natural History. He currently leads the Consortium for the Barcode of Life, an international network that uses systematics, genomics, and bioinformatics to develop DNA-based identification tools to make biodiversity information more widely available. Before joining the Smithsonian in 2000, he designed and implemented an international biodiversity and conservation program for the International Centre of Insect Physiology and Ecology in Nairobi, Kenya, and led the biodiversity programs at the Bishop Museum in Hawaii. He maintains an active research program as a curator of entomology at the National Museum of Natural History. He has published more than 190 publications and coedited four books. His current research focuses on moths of Papua New Guinea and Africa, especially the integration of systematics, ecology, biogeography, and conservation of insects and plants in Papua New Guinea. He is a cochair of the Interagency Working Group on Scientific Collections. He serves on the boards of the Friends of the National Zoo, the American Entomological Institute, and the Mpala Research Center in Kenya. He is a fellow of the American Association for the Advancement of Science and the Royal Entomological Society of London. He holds a B.A. from the University of California, Santa Barbara, and a Ph.D. in biology from Harvard University.

James M. Reilly is the founder and director of the Image Permanence Institute (IPI) at Rochester Institute of Technology in Rochester, New York, a world leader in preservation research since 1985. He is well known for his own research on deterioration of nineteenth-century photographic prints. Under his guidance, IPI has made important contributions to image preservation, management of film archives, environmental monitoring and control, and sustainable preservation practice. He oversaw the creation of the Preservation Environment Monitor datalogger and Climate Notebook software, which were supported by the National Endowment for the Humanities, the Mellon Foundation, and the Institute of Museum and Library Services. During its tenure, he was codirector of the Advanced Residency Program in Photographic Conservation, a program comanaged by the George Eastman House International Museum of Photography and Film. He is the author of numerous publications, including *Care and Identification of 19th-Century Photographic Prints*, “Preserving Photographic Collections in Research Libraries: A Perspective,” *New Tools for Preservation: Assessing Long-Term Environmental Effects on Library and Archives Collections*, *IPI Storage Guide for Acetate Film*, and *Storage Guide for Color Photographic Materials*. He is a consultant to many cultural institutions and is sought after worldwide as a teacher and seminar speaker. He was given a Technical Achievement Award from the Academy of Motion Picture Arts and Sciences in 1998, was presented with the Silver Light Award for Lifetime Achievement from the Association of Moving Image Archivists in 2002, and was the first winner of the Hewlett-Packard Image Permanence Award from the Society for Imaging Science and Technology in 2007.

Sarah Stauderman, director of collections, Hirshhorn Museum and Sculpture Garden, was formerly the associate director of collections care at the Smithsonian Institution Archives. She

focuses on preservation management for the wide variety of materials found in collecting institutions, especially electronic media, and maintains close ties to the communities who create, collect, and conserve cultural property. She has lectured widely on the preservation concerns of videotape and audiotape and was a founding member of the Electronic Media Group of the American Institute for Conservation. She has been an officer of the Washington Conservation Guild and served as a director on the board of the American Institute for Conservation.

William G. Tompkins, director, National Collections Program, Smithsonian Institution, serves as an advisor to Smithsonian senior management, unit directors, and staff on matters relating to collections management. With 30 years' experience at the Smithsonian, he strives to improve the overall stewardship and management of Smithsonian collections by providing central leadership, policy oversight, strategic planning, and support of Smithsonian-wide collections initiatives. He is responsible for the development, administration, and implementation of collections management standards at the Institutional level, including the review and approval of individual Smithsonian collecting unit policies to ensure collections are acquired, maintained, and used according to Smithsonian policy, professional standards, and legal obligations. Previously, he served as assistant director of the Smithsonian's Office of the Registrar and as the collections manager of the National Numismatic Collection at the National Museum of American History.

R. Robert Waller, CAPC, FIIC, is currently president and senior risk analyst with Protect Heritage Corp., a firm dedicated to helping institutions and organizations improve heritage management. His career includes 33 years with the Canadian Museum of Nature, which included periods as chief of the Conservation Section and as managing director of the Collection Services Division. He holds appointments as a research associate at the Canadian Museum of Nature and as an adjunct assistant professor in the Art Conservation Program at Queen's University. He holds a Ph.D. in cultural property risk analysis from Göteborg University and professional accreditation with the Canadian Association of Professional Conservators. His research interests center on risk analysis approaches to rational decision making for collections management and preservation. He has taught, lectured, and served as a consultant at museums and universities throughout North America, Europe, Asia, Australia, and New Zealand. He is a fellow of the International Institute for Conservation and has recently received the Carolyn L. Rose Award for lifetime achievement from the Society for the Preservation of Natural History Collections.

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