The Ideal Climate, Risk Management, the ASHRAE Chapter, Proofed Fluctuations, and Toward a Full Risk Analysis Model

By Stefan Michalski

Introduction

The conventional (late-twentieth-century) approach to climate control specifications for museums has been to find a single target associated with "ideal" conditions and, failing that, to specify "compromise" or "relaxed" conditions. It was assumed that the further one strayed from the ideal target, the greater the damage to the collections. Despite a steady undercurrent of thoughtful critiques from the very beginning of the climate control boom in museums (e.g., Rogers 1976) this fundamentalist approach to specifications has proven remarkably persistent.

Much of the success of a simplistic approach has nothing to do with whether or not museums actually believe that ideal control is ideal for collections, but with the fact that a single target makes life much easier for architects, HVAC engineers, curators, collection managers, exhibit designers, preparators, and, not least, conservators. I do not mean simply operationally easier in museums where it is achieved but intellectually easier in any museum, whether it is achieved or not.

Many decades have passed since the encouragement of the first magic numbers for climate control in museums—the 60°F, 60% relative humidity (RH) rule of Rawlins, (Rawlins 1942)—and the last three decades have seen widespread implementation of museum climate control "improvements." An entire generation of conservators and conservation scientists have watched the accumulation (or not) of damage in collections modified (or not) by climate control. The next generation faces painful decisions about sustainability. It is time to take stock and to consider what advice to pass on.

History of the ASHRAE Chapter

Until recently, climate specifications for museums and archives in the American Society of Heating, Refrigerating, and Air-Conditioning Engineers *ASHRAE Handbook* (the North American HVAC engineer's bible) was buried in a chapter on miscellaneous special applications. The advice was simple: provide 21°C and 50% RH, with minimal fluctuations. In 1996 work began on a separate "Museums, Libraries, and Archives" chapter for the 1999 edition (ASHRAE 1999). A revised edition, incorporating new material on pollution, appeared in 2003 (ASHRAE 2003).

At the time I was invited to be a member of the subcommittee responsible for the new chapter, the Canadian Conservation Institute (CCI) was considering a revision of its aging 1979 publication *Environmental Norms for Canadian Museums, Art Galleries and Archives* (Lafontaine 1979). Given the offer to work on the new ASHRAE chapter, however, a corporate decision was made to redirect all our efforts toward the ASHRAE text, whatever travel and time were necessary. The goal was a practical consensus between the conservation community and the engineering community, reached within a forum with vast experience in formalizing and legitimizing such texts, with guaranteed distribution to all HVAC engineers in the United States and Canada. I became the lead author of the section related to temperature (T) and RH specifications. A senior member of the ASHRAE publication's staff confided to me that I was lucky, that I should make the most of it, since writing a new chapter was much less painful, and much less common, than the endless revisions of an existing chapter.

Novel Elements in the ASHRAE Specifications for T and RH

Several novel elements were developed during work on the chapter, based on the conservation research of the time, a desire to incorporate some risk management principles, and common knowledge of the profession. Principal in the category of common professional knowledge was a growing admission among those with long museum experience that many collections survived well in conditions that were not ideal, that even museums that claimed to reach the ideal could not, and that the need for cold storage of many collections was sidelined in the drive to a single ideal. Overall, one sensed that users wanted a specification that somehow dealt with reality rather than with an ideal.

While considering the severe restrictions of chapter length, we reviewed all the relevant deterioration science. A conscientious effort was made to find reliable common ground in areas of controversial research in which I myself was active, such as the issue of mechanical response to fluctuations. Engineers were introduced to low-tech solutions peculiar to museums, such as RH buffered enclosures and cocooned spaces, as well as to unfamiliar diagrams: a psychrometric chart with isoperms and a constant equilibrium moisture content (EMC) line for archives, time for mold growth versus RH, as well as hygrometric half time of buffered and unbuffered cases.

The centerpiece was a large table called "Temperature and Relative Humidity Specifications for Museum, Gallery, Library, and Archival Collections (ASHRAE 1999, 20.6, table 2; ASHRAE 2003, 21.13, table 3). The following novel elements appeared in this table:

Set Points Can Vary from the Standard

Under the column "Set point or annual average," for the option "General Museums, Art Galleries, Libraries and Archives: All reading and retrieval rooms, rooms for storage of chemically stable collections, especially if mechanically medium to high vulnerability," one finds the following set points and notes (ASHRAE 2003, 21.13, table 3):

- 50% RH (or historic annual average for permanent collections);
- T: A value between 15°C and 25°C;
- (*Note:* rooms intended for loan exhibitions must handle set point specified in loan agreement, typically 50% RH, 21°C, but sometimes 55% RH or 60% RH)" (ASHRAE 2003, 21.13, table 3).

This specification recognized three realities:

- That collections can acclimatize to an average annual RH other than the central value of 50% RH (in terms of mechanical response, and presuming moderate deviation);
- That T set points need not be at a universal value dictated by human comfort, i.e., 21°C;
- That rational behavior for one's own collection said nothing about contractual realities of loans, which themselves are not universal.

The Risks of Each and Every Climate Control Option Are Provided

The table provides numerous options, both in the set points and in permissible fluctuations. For each option, the table provides collection risks/benefits and describes the climate-related risks that have been avoided and those that are still present. Thus, a user cannot select an option, even the so-called ideal, without being notified in the table of any unresolved risks to the collection.

The Archive Risk Is Repeated for All Moderate Temperature Options

All five options based on a moderate T set point repeat the fact that these do not address the needs of chemically unstable objects, but the details vary. For example, although the option with very wide seasonal temperature swings notes the added risks from high summer temperatures, it also notes the benefits of low winter temperatures.

A Wide Range of Options for Seasonal Adjustments for Energy Efficiency

Seasonal setbacks have been a part of climate specifications for some time (e.g., CCI Technical Bulletin, Environmental Norms for Canadian Museums, 1979), but in this chapter, the range and variety of options were greatly increased, and they were integrated with the specifications for short fluctuations.

Fluctuations AA, A, B, C, and D: Something for Everyone, from Rich to Poor

The single most contentious issue in drafting the specifications was my proposal for a wide range of specified fluctuations, labeled AA, A, B, C, and D. Although most members of the committee supported the notion, one member from the engineering side was strongly opposed. The disagreement was not so much about whether such a wide range of fluctuation options was meaningful in terms of a performance specification for a system plus building plus intelligent controller, but whether or not it was the role of ASHRAE to specify anything beyond the performance of the system at a fixed set point, under the design load (which should always be within a narrow range of fluctuations). With the support of the chapter committee chair, as well as that of the volume committee above us, the concept of different "qualities" of climate control was accepted, and this concept was ratified by subsequent review stages with the ASHRAE membership at large. I felt that we had finally brought the reality of all scales of museums into a rigorous climate control specification. The benefits of even the most modest elements of climate control were given legitimacy within a handbook dedicated to the principle of technological solutions, but with a clear-eyed recognition that risks increased—that is, risks to the collection; within larger risk contexts of the museum and the world, these options arise because total risk is reduced. My impression was that we were not the only committee recognizing that solutions need not be grand.

The options B, C, and D provide guidance to smaller museums or guidance for more vulnerable buildings. B addresses the issue of cold climates, where very low winter temperatures are preferable to very low RH. The option C addresses the museum that wants to control just RH and keep within the two knees on the sigmoidal curve at 25% and 75% that we know represent rapidly increasing risks of various types. The lowest form of control, D, considers what I think is the single greatest risk worldwide from incorrect climate—mold.

<u>Option B</u>

Precision control, some gradients plus winter temperature setback

± 10% RH, ± 5°C. Seasonal adjustment: up 10%, down 10% RH; up 10°C, but not above 30°C, down as low as necessary to maintain RH control.

Collection Risks and Benefits: Moderate risk of mechanical damage to high vulnerability artifacts, tiny risk to most paintings, most photographs, some artifacts, some books and no risk to many artifacts and most books. Chemically unstable objects unusable within decades, less if routinely at 30°C, but cold winter periods will double life (ASHRAE 2003, 21.13, table 3).

Option C

Prevent all high risk extremes. Within range 25% RH to 75% RH year-round, Temperature rarely over 30°C, usually below 25°C.
Collection Risks and Benefits: High risk of mechanical damage to high vulnerability artifacts, moderate risk to most paintings, most photographs, some artifacts, some books and tiny risk to many artifacts and most books. Chemically unstable objects unusable within decades, less if routinely at 30°C, but cold winter periods will double life. (ASHRAE 2003, 21.13, table 3).

Option D

Prevent dampness. Reliably below 75% RH.
Collection Risks and Benefits: High risk of sudden or cumulative mechanical damage to most artifacts and paintings due to low humidity fracture, but high humidity delamination and deformations, especially in veneers, paintings, paper and photographs will be avoided. Mold growth and rapid corrosion avoided. Chemically unstable objects unusable within decades, less if routinely at 30°C, but cold winter periods will double life. (ASHRAE 2003, 21.13, table 3)

Why AA and A?

An initial draft used the letters A, B, C, D, and E for the five classes of control, with the topmost class (A) reflecting the conventional "ideal" of very small fluctuations. At the time of writing, conservation scientists (Michalski 1993; Erhardt and Mecklenburg 1994) and conservators (various personal communications) were in agreement that the traditional ideal was too tight and that slightly wider fluctuations, including modest seasonal setbacks, were very low risk and probably completely safe. I began to think of this as the "optimal" control level rather than the ideal. My sense was that we could not yet abandon the tight ideal specifications, since it was plausible that a very small risk of damage was avoided, in comparison to the optimal control, and if a flagship museum wanted to pay for that marginal benefit (or had, in fact, paid for it already), then we should not deny that some benefit may have accrued. On the other hand, we did not want to saddle those seeking what was widely seen as optimal, and probably zero risk for many collections, with the unhappy letter designation of B. I borrowed from the psychology of the credit rating system: AAA, AA, A, B, C—that is, a major museum, trying to be conscientious, should not feel that the optimal level A is inadequate or that it represents much change from AA. Drops to level B or C were meant to feel like bigger jumps in risk, as indeed they are.

Option AA

Precision control, no seasonal changes. Short fluctuations ± 5% RH, ± 2°C. Seasonal adjustment to set points: RH, no change. Up 5°C; down 5°C.

No risk of mechanical damage to most artifacts and paintings. Some metals and minerals may degrade if 50% RH exceeds a critical RH. Chemically unstable objects unusable within decades. (ASHRAE 2003, 21.13, table 3)

Option A

Precision control, some gradients or seasonal changes, not both. Short fluctuations ± 5% RH ± 2°C. Seasonal adjustment: up 10% RH, down 10% RH, up 5°C, down 10°C

OR ± 10% RH ± 2°C. Seasonal adjustment: RH no change, up 5°C; down 10°C

Small risk of mechanical damage to high vulnerability artifacts, no mechanical risk to most artifacts, paintings, photographs, and books. Chemically unstable objects unusable within decades. (ASHRAE 2003, 21.13, table 3)

The two different options for fluctuations, which one may notice do not add up equally, was based on the fact that the organic materials susceptible to fracture and deformation, such as wood and paints, have stress relaxation times on the order of a few months at moderate T and RH, so a fluctuation of ± 10% RH over a season was estimated to create at most half the stress of a ± 10% RH daily/weekly fluctuation, equivalent then to ± 5% RH as a short fluctuation.

Combining Conrad's Classification of Buildings with the ASHRAE Control Levels

Although some suggested that there was no need for any discussion of the building envelope, since it has its own chapter in the ASHRAE fundamentals volume, others felt that the preponderance of historic buildings in use by museums required some mention. We used the best available summary: Conrad's table of five classes of buildings in terms of their ability to accommodate museum climate control. (ASHRAE 2003, 21.14, table 4) We added a final column to the table listing the classes of control (AA, A, B, C, D) that were possible for each of the building types, given various climate regions. Users of the chapter would not be able to forge ahead with a proposed level of control for an old building before considering the fundamental issue of whether or not the building could support it. We also noted the *New Orleans Charter for Joint Preservation of Historic Structures and Artifacts* (formulated in 1990–91), which raised the question of whether the building should support it.

A Risk Management Approach to Climate Control

The ASHRAE Chapter: Informed by and Informing Risk Management

The following section briefly considers the risk management approach to climate control, elements of which informed the ASHRAE chapter. One can read the ASHRAE specification table not only as a prescription for avoiding various risks but also as a description of risks, given existing levels of climate control. If, for example, one has a collection currently subject to a level of control of D—that is, all one can say is that conditions are "reliably below 75% RH"—then a preliminary risk assessment is as given in the "*Collection Risks and Benefits*" for D (ASHRAE 2003, 21.13, table 3)

When I teach collection risk assessment courses, I always use the ASHRAE chapter and its specifications table to inform an exercise about assessing risks to a collection when climate control is "not ideal."

Thinking about What Can Go Wrong, Rather Than What Is Best

What is the ideal climate for a historic tool made of iron and wood? Or a watercolor on display that we know fades much more slowly at low RH? If by *ideal,* one means *perfect,* there is none. What about the fact that the tool is used in the woodworking reenactment? Or that I have to reduce the costs of winter heating and summer cooling?

Common sense and experience teach us to approach such dilemmas from the perspective of questioning, rather than seeking ready answers: What can go wrong? Which problem is biggest? How can I reduce it? Risk management formalizes this intuitive approach.

The originator of the magic numbers in museum climate control, Rawlins (1942) admitted in his influential article an "inability to suggest a minimum temperature at which a building should be maintained." He noted that "many materials accustom themselves fairly well, so long as large . . . variations in RH and temperature are avoided." He concludes, however, by finding "acceptable conditions . . . are 60°F, 60%. (Which incidentally, is easy to remember.)"

What had begun as an argument based on avoiding what can go wrong—that is, a risk based argument—became a single set of easy-to-remember numbers—namely, an ideal target. By the 1970s, specifications formalized the tiny size of this ideal target at ± 3% RH , ± 1°C, based not on any collections needs analysis but on the switching differentials of the best-available HVAC systems. No one really understood the costs that would emerge.

Risk and Hazard

A risk has two parts: the hazard and its impact. When assessing risk, one combines the likelihood or frequency of the hazard with the scale of the impact (also called consequence, loss). Although we tend to associate the word *risk* with individual events, it can be applied to continual and intermittent losses if one specifies some time horizon (such as ten years or one hundred years) for the assessment of whatever has accumulated.

The Risk Management Process

Risk management can be divided into stages. Within the terminology of current international standards for risk management (AS/NZS 4360:2004) these are:

1. Establish the context
2. Identify risks
3. Analyze risks
4. Evaluate risks
5. Treat risks (control, reduce, mitigate, etc.)

Stages 2, 3, and 4 constitute risk assessment. Throughout this process, one must also (1) communicate and consult, and (2) monitor and review.

In hindsight, it is not difficult to see that a risk management framework can structure all the issues that emerge during climate control dilemmas in museums.

Museum Climate as Hazard: Incorrect T and Incorrect RH

RH and T are not in themselves hazards, despite the tendency in our field to speak loosely about RH (or T) causing damage. A means for expressing climate control issues as hazards was developed within Michalski's (1994) schema for nine agents of deterioration, where one finds "incorrect temperature (T)" and "incorrect relative humidity (RH)." Within these, a few subtypes were proposed:

Three types of incorrect T:

- too high;
- too low;
- fluctuations about a mean.

Four types of incorrect RH:

- damp;
- above and below a critical value;
- above 0%;
- fluctuations about a mean.

These types were not intended as rigorous material science categories but as practical aids for grouping hazards during identification and control.

Proofed RH and Its Application

It Can't Get Any Worse—Can It?

The proofed RH or T is the largest RH or T fluctuation to which the object has been exposed in the past or, alternatively, just the lowest and highest RH and T of the past. The risk of further mechanical damage (beyond that already accumulated) from fluctuations smaller than the proofed value is extremely low. If the past fluctuation was enough to cause fracture, the object has fractured, and the crack just opens and closes. When built on purpose, such openings are called expansion joints. If the past fluctuations did not cause fracture and the material strength has not changed much, then there is no reason to expect a future fracture in response to the same fluctuations. In summary, if the future climate conditions do not exceed the range defined by past conditions, then the risk of future mechanical damage is negligible.

(Risk of increased mold damage and risk from chemical aging damage is not at all the same, and they have their own practical climate control concepts.)

In various workshops and articles (Michalski 1993, 2004),I have used this concept of “proofed” fluctuation to provide a powerful shortcut past any need for elaborate (and impossible) mechanical response calculations— instead going straight to a risk assessment based only on past climate records. And of course, this approach resonates with the belief, the hope, that collections “acclimatize.” Collection managers of historic house museums have reported that they have found the concept useful, since it reduces the emphasis on “improving” climate control. I admit, however, that I have not provided much detailed justification. Here I explore the concept further, as well as consider its application and possible limitations.

Pretending to Have Had Better Climate Control Is Counterproductive

The value of proofed fluctuation makes it clear that denial of any past poor climate control in a museum is extremely counterproductive during risk assessment, since the more optimistic (small) are the stated fluctuations of the past, the higher the estimate of future risk. In the spirit of Reilly's aphorism for climate control thinking in archives, where "Archives remember the bad times" (James Reilly, Image Permanence Institute, pers. Comm., 1981) (since even short high-RH and high-T events determine lifetime), we can add one for furniture, paintings, and all those mixed collections susceptible to fracture from fluctuations: The worse their past, the better their future.

Proofed Value Says Nothing about the Risk of Larger Fluctuations

The proofed fluctuation concept makes no prediction of the risk of mechanical damage beyond the proofed value, other than saying that high risk is now possible. The scale of this risk requires independent analysis.

Proofed Value Is Global and Knowable

The proofed value concept is practical because:

- it applies globally to a mixed collection of wood and paint, whereas an estimate of risk based on a predictive model of an object's materials and assembly is object specific, highly complex, and in many cases beyond current knowledge;
- the past values of RH and T are knowable, at least in principle, and often in practice; it provides a practical guide to the benign region of future climate.

Proofed Value Is Individual as Well

The simplest model of fracture probability for a single cycle test gives a "bathtub curve." This is a sharp, U-shaped curve, with stress or the driving force, such as RH fluctuation, on the x-axis, and probability of fracture on the y-axis. The single systematic study of such curves in museum objects, by Williams (1991) studied the fracture of large numbers of fresh mammalian teeth during slowly falling RH. When replotted as percent fractured versus RH by Michalski (Michalski 1993), the data showed remarkably sharp cumulative distribution curves: between 10% and 90% of samples cracked in a range of only a few percent RH (when separated by tooth type—canines, molars, etc.). In other words, the variance of the fracture RH, within a group of objects that were relatively similar in material and geometry but not identical, was very narrow. So for fracture of an object that was identical, such as the artifact itself in the future (compared to itself in the past), we can reasonably assume that the fracture RH has not randomly changed to some new value because of some inherent uncertainty process. Although this may seem a self-evident argument, there is a tendency to see all mechanical fracture as some kind of highly variable, butterfly-influenced phenomenon, rather than a well-behaved phenomenon that does, admittedly, show considerable variance in traditional tensile tests with imperfect samples and imperfect jaws. Proofed fluctuation applies globally, but it also applies to each object.

Correction Due to Fatigue from Multiple Fluctuations

Fatigue fracture due to repetitive fluctuations has been used by Michalski (1991) to estimate the cumulative damage possible due to fluctuations below the critical fluctuation that causes fracture in one cycle. The fatigue literature provides many S-N curves for materials, where *S* is the stress leading to fracture, plotted on the y-axis, and *N* is the number of cycles to cause fracture at that stress (plotted logarithmically on the x-axis). The general curve shape is sigmoidal, starting from the stress for fracture in one cycle and dropping to a plateau where cyclic stress can be tolerated indefinitely. This lower plateau begins typically in the range of 1 *M* to 10 *M* cycles, at a stress of ¼ (for tough materials) to 1/10 (for brittle materials) of the single cycle stress. Fatigue complicates the proofed value concept by adding a range of values less than the proofed values which may lead to fracture if repeated sufficiently. This fatigue correction to the proofed value will be pessimistic—it will reduce the safe zone to less than the simple estimate of proofed value—but I anticipate that the correction is modest and will not change the practical application of the concept. The S-N curve shows that a small reduction below the stress needed for single cycle fracture makes a huge increase in the number of cycles needed. It may be, however, that the most precise formulation of the concept is based on a pattern of previous fluctuations—a proofed frequency distribution of fluctuations—rather than on a single parameter. That is to say, the phrase "previous fluctuation history" may be a precise predictive concept only when considered as a full pattern, rather than just as a reduced parameter, such as peak values.

Correction Due to Stress Relaxation

Stress relaxation data are available for many materials of interest, although precision is poor. In common terminology, the degree of stress relaxation of materials determines the relevance of object "memory" of conditions at manufacture, or those of its recent past, where "recent" means on the order of the relaxation time constant(s) of the objects. As a correction, it means that the proofed RH must be interpreted as a fluctuation above or below the average RH and T of the recent past, rather than some older value, or perhaps the annual average value. This correction may be either pessimistic or optimistic: for past extreme fluctuations that were embedded in seasonal drift, such as winter low RH, the fluctuation relative to the previous three-month average is smaller than the fluctuation relative to the annual average. For extremes that are counter to the seasonal trend, such as a rare low-RH extreme in summertime, the proofed fluctuation is larger than computed from the annual average. As with the fatigue correction, the best analysis may be to consider whether future climate conditions and past climate conditions in a museum are the same not only in terms of extreme values but also in terms of the patterns preceding these extremes.

Fluctuations Too Short to Be Used for Proofed Fluctuation

Many extreme fluctuations in the past were "short"—that is, they lasted less than the response times of some objects in the collection. Such events cannot be used to fix the proofed equilibrium RH; they can only provide a proofed RH of a certain duration. A necessary analysis of thermohygrograph data would therefore provide not only the event frequency of each amplitude of fluctuation but also its duration. To a first approximation, duration and frequency are correlated; a Fourier analysis (frequency spectrum) of the thermohygrograph "signal" would provide duration as the reciprocal of frequency, but a more probabilistic approach, using short and long "square wave" events, with the possibility of summation of events, probably will be more fruitful, as well as easier to model in terms of how we typically interpret charts—seasonal values with shorter events superimposed. Each collection has a distribution of response times, and many of these are predictable, certainly to within useful categories such as an hour, a day, a month, or longer.

Too Much Uncertainty?

Uncertainty about collection climate history obviously determines the usefulness of the proofed fluctuation concept. At present, however, the author does not expect that such corrections will change practical advice, such as telling a museum in a historic house in a cold climate that they are probably wrong to "improve" HVAC control if their mixed collection has gone to 10% RH for most of January every year in the past ten years, or if it has gone to –20°C each winter. Interesting subtleties may arise, however, when the "tail" of climate data suggests that a hundred-year extreme low T may cause the indoor RH to drop below the proofed low RH.

Conservation Treatment Erases Proofed Fluctuation!

The final, and perhaps most controversial aspect of the proofed fluctuation concept is the way it can be nullified by well-meaning conservation treatments. Furniture conservators and paintings conservators are well aware of the problem of treatments being "repeatedly erased by poor storage conditions," but the other side of the coin is this: given unavoidable climate conditions in a museum, treatments erase the safety margin achieved by the fractures from historical conditions. One must begin to distinguish consolidation treatments that make the object less vulnerable to RH fluctuations from those that make it "stronger" during handling—but much more vulnerable to the less easily mitigated risk of future fluctuations.

Conclusion

Toward a Risk Analysis Model

The current drive in my work at CCI is the development of risk assessment tools, in partnership with the International Centre for the Study of the Preservation and Restoration of Cultural Property (ICCROM) and the Netherlands Institute for Cultural Heritage (ICN). We are working with an external risk analysis expert, G. Paoli, to develop models of collection risk, using Analytica, a software package widely used in the risk analysis field. Analytica deals explicitly with uncertainties in expert judgments of each variable, through user-selected probability distributions, and it can also model dynamic (feedback) systems.

The main focus over the past years has been in developing an overall risk model that can simply accept expert judgments on various risks, as well as accept predictive submodels when they are available. Such "hybrid models" are becoming common in risk analysis. We have started, for example, on a model of paper aging from excessively high T, since the mechanisms and parameters are well researched.

Risk models for fluctuations will be explored. My sense is that one can model most of the risks without necessarily having a moment-by-moment characterization of RH and T values but by simply having a probability distribution function of the T for chemical pathways and a probability distribution of fluctuations and their associated intensities. These requirements may seem to constitute a heavy burden at first glance, but within manageable uncertainty, it is really about the climate patterns we know so well, anchored at one end of the spectrum by diurnal fluctuations and at the other end by seasonal fluctuations. Even without any elaborate modeling of complex artifacts, one will be able to model all the corrections outlined in the section on proofed fluctuation. Along with a model of enclosure leakage and hygrometric lifetime, one will be able to model the risk mitigation possible by ensuring that the fluctuation at the artifact is less than the proofed fluctuation. At the very least, a model can use the expert judgments of risk published in the ASHRAE chapter for classes AA, A, B, C, and D.

Classic dilemmas of risk-risk tradeoffs then become a matter of modeling each risk and finding the point of minimum total risk: What is the balance between elevating T to prevent mold in damp climates and depressing T to reduce chemical self-destruction? The balance between light fading risk that lowers at low RH and fracture risk that climbs at low RH? And so on.

Toward Assessment and Acceptance of Loss

Even if, as scientists and advisors, we successfully quantify all these issues, my experience to date in risk assessment training has taught me that the uncertainty and the difficulty in these risk assessments do not reside in the material science, difficult and incomplete though it may be. The largest uncertainty resides in estimates of the loss of value: how does mold loss compare to embrittlement and severe yellowing? How does color loss compare to paint flaking? Which loss do you prefer? And which costs more to solve? The list is endless. The problem with taking museums away from the belief in an ideal collection climate and its parent, perfect preservation, is not that it was ever a reality but that it was a great comfort.

Author Biography

Stefan Michalski holds an Honours BSc in Physics and Mathematics (1972) from Queen's University in Kingston, Ontario. He trained as an artifact conservator at the Master of Art Conservation program at Queen's University. He joined the Canadian Conservation Institute (CCI) in 1979 and is currently senior conservation scientist in the Conservation Research division at the CCI. He has researched museum environmental issues for twenty-five years and provided advice to conservators, architects, engineers and collection managers, and surveyed numerous collections and their facilities. He is currently working in partnership with ICCROM to develop a Web-based manual for risk assessment.

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