The Museum Environment: Transforming the Solution into a Problem

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Abstract The museum environment is a complex subject that cannot be reduced to a simple set of requirements. The enforcement of prescriptive and rigid environmental specifications can result in unintended and adverse consequences, both to the collection and to the overall institution. Although there are practical reasons why guidelines have transformed into rigid specifications, the emphasis needs to shift back to flexible performance-based guidelines.

The successful application of performance-based environmental standards can only be accomplished if conflict is avoided within the planning process. This can be achieved through improved communication and collaboration, which must be initiated at the outset of the process. Also, improvements in how the museum environment is taught are necessary, with an emphasis on the planning process, risk management, and an extensive technical understanding of how environmental control is achieved.

Within the last forty years, there has been a tremendous increase in awareness throughout the world about the need to control the museum environment to preserve collections. Overall, the implementation of environmental controls within museums has had a huge and positive impact on the stabilization of museum collections. This trend was given a huge boost in 1978, when Garry Thomson published *The Museum Environment* (1978). Thomson's book provided a thorough and excellent summary of knowledge to date on the subject. Although the book included very specific environmental specifications that museums should strive to achieve, Thomson's technical explanations for the basis of these values provided enough information so that museums could interpret and select values that differed from

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his specifications but were more appropriate to their unique climate, building, or budget.

But, as in so many aspects of life, the zealous and successful pursuit of a worthy goal often gives way to the *law of unintended consequences*, whereby positive progress is partially offset by negative and unforeseen results. In 1986, a second edition of Thomson's *The Museum Environment* (1986) was published containing a convenient summary of specifications as an appendix. It is no longer necessary to read the book to find individual specifications since they are precisely summarized in two pages. The problem is that without fully understanding the logic behind environmental specifications, they rigidify into regulations that have to be met, regardless of whether they make sense for a particular application.

Although a world of rules and regulations is generally preferred over a world of anarchy, it is far better to live in a world where rules make sense and achieve the purpose for which they were intended. The first section of this article will review some of the more common environmental specifications for museums, describing some of the unintended negative consequences of their implementation and how such problems can be avoided. The second section will discuss the kind of knowledge and training that is necessary for improving our understanding and implementation of environmental standards.

From Flexible Guidelines to Rigid Specifications

The extraordinary growth in popularity of museums around the world over the last forty years has been accompanied by a tremendous growth in the number and size of museums and the number of traveling temporary exhibitions. There also has been a large increase in the number of conservators, registrars, and collections managers and an increasing appreciation, especially among these core groups of specialists, about the need to control the museum environment in order to preserve collections. These developments have contributed to the reframing of informal environmental guidelines into formal and precise environmental specifications. The driving force for this transition is primarily due to four factors:

The physical growth of museums—It is not a simple and inexpensive matter to upgrade the climate control system in an existing building so that it can provide good control of relative humidity and air pollutants. Therefore, the ideal time to introduce good environmental conditions is when the museum is planning major renovation or new construction. As part of the architectural design process, the architect and mechanical engineer will request a climate specification from the client that can be incorporated into the plan. It is not sufficient for the client to simply say that they would like *humidity control*. An engineer does not deal with generalities. The engineer requires a specific relative humidity range in order to design an appropriate system.

Traveling exhibitions—Along with the huge increase in the request for loans between museums was the increasing awareness of the risks involved in such loans. In order to reduce risk, many museums began to place certain requirements on the borrowing institution, such as the need to maintain good environmental conditions. This resulted in the need to provide specific values for the level of light, temperature, and relative humidity that would be incorporated into formal loan agreements.

Expansion of the conservation and collections management profession—The role of specifying environmental conditions for collection preservation ultimately falls on the conservation and collections management specialists. As the number of collections management and conservation training programs and museum positions has expanded, there has been a large increase in the cadre of advocates and enforcers of environmental standards.

Growth of awareness about the importance of environmental control by museum professionals—Museum professionals who are not specialists in preservation are not in a position to know all the literature on the environmental needs of collections. Therefore, they look to the collections management and conservation specialists to distill complex discussions into simple rules and numbers that can be followed.

As a consequence of the developments described above, common sense, flexible guidelines, and best efforts to provide a good museum environment have morphed into rigid specifications. This observation is not a negative comment on the current state of affairs. In fact, quite the opposite, these developments have resulted in great progress regarding the state of preservation of museum collections. Although there are practical reasons why it was both inevitable and necessary to create a simple set of enforceable environmental requirements, we also must be aware of the negative consequences of rigid specifications.

A Choice of Words

When dealing with the museum environment, it is important to be clear about the distinction between a *guideline*, a *standard,* and a *specification*. A *guideline* or a recommendation is generally perceived as flexible. It suggests a goal that one should strive to achieve, regardless of whether the exact condition is actually met. A *specification* is perceived as a precise and rigid requirement that must be met. Falling short of a specification implies failure. Success is no longer measured by best effort, but by the ability to achieve the specified condition.

The concept of an *environmental standard* for museums lies somewhere between a guideline and a specification. It is an ambiguous term that can be easily misunderstood, especially in a field such as museums where a very broad range of environmental conditions exists. If the term *museum standard* refers to published environmental specifications determined by a consensus of professionals, the standard tends to be interpreted as a requirement. If a standard refers to what most museums actually do as standard practice, the meaning and purpose becomes less clear since common practice does not necessarily mean best practice.

Thomson's selection of the term *specification* in preference to *guideline* in *The Museum Environment* was unfortunate because it encouraged a rigid interpretation and application of his environmental recommendations. A rigid rule or value, when enforced without regard for context, can result in unforeseen and negative consequences. But, it was also necessary since a rigid rule ensures that environmental values are not ignored or unnecessarily compromised.

The Law of Unintended Consequences

There are three categories of negative and unintended consequences that commonly occur when environmental specifications are rigidly applied, without regard to whether their precise implementation is the best option for the preservation of collections.

Category 1/Inaction.—As an example, instead of installing simple equipment that provides enough control of humidity to avoid extreme conditions, many institutions will wait until they can obtain major funding for a full environmental upgrade that allows them to achieve the narrow band of relative humidity control required by a typical museum environmental specification. Rather than affecting a partial solution immediately, the institution will wait for an ideal solution, even if it means doing nothing for many years. While this may be a laudable attitude, an excessive delay can result in negative consequences. The advantage of implementing affordable temporary solutions must be carefully weighed against the risk to collections as a result of delaying any improvements for a long period of time.

Another example of inaction involves the private collector. Most collectors realize that it is not possible to achieve a narrowly specified *museum condition* in their private residence, and therefore feel that it is beyond their capability. If they understood that a more flexible approach, falling far short of a rigid museum environmental specification, would significantly reduce risk to their collections, they may be more willing to implement such a solution.

Category 2/Collateral Damage.—Environmental specifications for museums provide solutions for preserving collections. For example, a specification requiring 50% ± 5% RH is intended to stabilize the condition of objects made from organic materials. It does not take into account the effect of maintaining 50% RH on other factors such as the building. If the building envelope is not designed with vapor barriers, insulation, and thermally insulated glass, the building will be at risk of damage from condensation during cold winter months. Typically, this sort of situation presents a dilemma for historic house museums where the historic structure is at least as important as any of the furnishing within. If the historic fabric of the structure has to be modified so that an elevated interior RH can be safely maintained, these physical alterations to the structure also can be considered as a form of irreversible damage. This is not to say that the introduction of humidity control should be avoided entirely in such a case. Rather, it is important to balance needs and consequences so as to avoid doing damage instead of blindly pursuing a program of trying to protect collections against damage.

Category 3/Misallocation of Resources.—Environmental specifications are not listed in a hierarchical order of priority. As a result, if an institution has limited resources to implement improvements, it may not be clear how to best allocate limited funds. For example, the high cost of installing and maintaining a sophisticated multi-zoned climate control system may deprive the institution of funds that could have also been used to upgrade poor quality storage equipment. The goal is to preserve collections, not to meet published museum specifications. To this end, risk analysis should be undertaken to weigh priorities and balance needs in order to determine the best use of limited resources.

The three categories of unintended and negative consequences described above can be avoided. But, it takes knowledge and experience to know when and how to implement environmental improvements, rather than simply insisting on a published number.

Prescriptive Specifications versus Performance Guidelines

Within the realms of construction and public safety, prescriptive specifications have been used to protect the public interest. A good example is local building code. A new building must meet specific code requirements in order to obtain a certificate of occupancy. In order to meet the code, architects, engineers, and contractors often follow a *compliance mentality*. This does not necessarily assure that *best practice* is used to provide the most appropriate solution for the problem that the code was intended to resolve. However, precise building code specifications have the advantage of being easily verifiable and enforceable.

Over the last decade, there has been increasing interest in performance-based standards. The goal is not to dictate how to achieve a specific objective but rather to assure that the objective is achieved. This approach allows more flexibility in developing solutions that are most appropriate to solving the problem. Performance-based standards are slowly being adopted by various industries, but issues remain due to the difficulty involved in enforcing them and the higher level of knowledge that is required to assure proper selection and implementation.

With regard to the museum environment, the most effective method for ensuring that the ultimate goal of preserving collections and avoiding unintended negative consequences is achieved is to shift from a prescriptive to a performance-based approach. Rather than insisting on specific temperature, humidity, or light values as stipulated in professional publications, it would be best to determine what makes sense for a specific context. This approach is not a rejection of published specifications. It recognizes that the published information is useful and important as a guideline on how a particular level of performance can be achieved. Existing specifications must be neither abandoned nor ignored. Rather, they should be applied intelligently, based on the realities of each unique situation. Examples, based on light and humidity, are discussed below to illustrate common misapplications of prescriptive specifications and to provide alternative models for achieving better performance.

Seeing the Light

Specifications for exposure of collections to light are based on assumptions about how much light is required by the general public to adequately view a museum object. On the basis of experience and a variety of studies, the most often quoted values range from 50 lux (5 foot-candles) for light sensitive materials to 200 lux (20 foot-candles) for moderately sensitive materials. These values have evolved into a rigid prescriptive standard. The performance-based logic behind these numbers is that any level of light in excess of the minimum amount necessary to adequately view an object on exhibition causes unjustifiable damage.

When confronted with a situation in which an object is displayed in a brightly lit room where the ambient daylight level cannot be reduced, which is the more appropriate action?

- The prescriptive approach: Reduce the level of task light on the object, in spite of the high level of ambient light in the space, to meet a specification. The negative consequence is the reduction in quality of the viewing experience.
- The performance-based approach: Increase the level of task light on the object, even if it exceeds the specification, so that the public can adequately view the object on display in the brightly lit room. The negative consequence is the difficulty in the ability to enforce a standard. Instead of basing light levels on a simple objective light measurement, the decision about an acceptable lighting condition takes us into a realm of complexity and confusion. For example:

- How do you measure subjective criteria about the quality of the viewing experience?
- Who determines what an adequate lighting condition is?

Nobody wants to deliberately light an exhibit so that it cannot be adequately seen. However, the negative consequences of a performance-based approach make the prescriptive approach preferable from the perspective of enforcing environmental standards. In reality, many museums tend to settle on some sort of compromise between prescription and performance, especially in galleries with varying daylight conditions. In the case of loan requirements where light levels are specified, prescriptive values are generally followed due to contractual obligations, regardless of negative visual consequences.

There are times when specifications and regulations miss the bigger problem they are meant to solve. Our fixation on the control of light levels as a means of limiting light damage is an example. It is worth repeating that the entire basis for controlling light is because *light in excess of the minimum amount necessary to adequately view an object on exhibition causes unjustifiable damage*. Rather than draw battle lines based on lighting an object at 50 versus 100 lux, we should be concerned with all the objects on exhibition that are illuminated during public hours when there are no visitors in the gallery.

Since light damage is cumulative, it is not the number of photons of light at a single moment in time that matters, but rather, the total number of photons over time that must be taken into account. Therefore, the goal should be to *make every photon count*. Museums consider this when light-sensitive objects are rotated and exhibit time is carefully controlled. The concern is rather for collections that are not rotated, yet not constantly viewed. Even museums with large attendance have many galleries with low or no attendance for large periods of the day. In these instances, the best strategy would be to reduce illumination on light sensitive objects when they are not being viewed.

Clearly, there are reasons why museums do not routinely reduce or shut off lights in galleries during public hours. There are a wide variety of issues regarding the practicality of this approach. If not done properly, occupancy-based lighting provides an abnormal and negative experience for the visitor. It also may be expensive to implement, depending on the electrical and lighting layout of the galleries. However, there are solutions to these problems if there is a strong commitment to solve them. For museums and gallery spaces with low or intermittent attendance, the ultimate preservation tool for light control is not strict adherence to a specified light level standard, but the elimination of light when it is not required. Sometimes, it is necessary to take a step back and make sure that we are fighting the right battle.

In the end, the battle is not about prescriptive specification compliance; it is about finding the best performance-based solution that successfully balances preservation and visual requirements.

Controlling Complexity: The Humidity Dilemma

In theory, the control of relative humidity (RH) should not be difficult for buildings with ducted air systems. If the RH is too low, add a properly sized humidifier to the air handler. If the RH is too high, set up a dehumidification sequence, in which the air is overcooled to remove excess water and reheated to control space temperature.

In practice, the control of RH is a complex affair that has consequences beyond the cost of upgrading climate control equipment. The selection of a relative humidity set point and acceptable RH range based on published or commonly utilized specifications can result in enormous problems for the building, the budget, and even the collections, if other key factors are not taken into account. Three examples described below illustrate some of these consequences.

The Building Envelope

The insulation characteristics of the building envelope play a fundamental role in determining the feasibility and cost of humidity control (Rose 1994). For buildings with inadequate vapor barriers, poorly insulated walls and windows, condensation will occur in a humidified building during cold weather when the surface temperature drops below the dew point. For example, if a specification of 70º F and 50% RH is established for an exhibit space, condensation will occur when a surface is at or below 50º F.

To prevent condensation, either the interior RH must be reduced or the building envelope must be modified to provide better insulation and vapor barrier properties. The cost of such an upgrade to an existing building is very high, and, in the case of an historic structure, the level of required architectural modifications to the original historic fabric of the structure may be unacceptable. Therefore, the ability to maintain a specification of 50% RH in the winter in many museums located in cold regions is not limited by the capacity of a humidifier, a problem that can generally be solved at moderate cost. It is limited by the building envelope design, which is a far more complex and expensive matter.

Rather than impose a rigid RH specification that cannot be maintained, it is important to analyze the building envelope to determine what level of RH can be maintained in cold conditions, and to what extent the building envelope can or should be upgraded. If the building has single pane glass, the safe level of RH may have to be maintained below 35% in the winter, depending on outside temperature conditions. Therefore, unless the single pane glass is upgraded to a minimum of a dual pane insulated window, this defines the upper limit of safe winter RH. The insulation and vapor-barrier qualities of all exterior surfaces must be similarly analyzed.

A cost-benefit analysis must be carried out to develop a series of options.

This type of study must take into account the extent that components of the building envelope can or should be modified to maintain various levels of interior RH under extreme outside temperature conditions. Through a combination of select envelope improvements and seasonal adjustments of the RH set point, various options for internal RH conditions can than be modeled to determine which options place the collections at an unacceptable level of risk and are absolutely unacceptable, and which option provides the best cost-benefit solution.

The Budget

In the previous section on the building envelope, it is clear that the introduction of humidity control has a large impact on building construction costs. Another factor that drives up the cost of a system is the precision of the climate control system. A system that must maintain a constant temperature and relative humidity condition within a very narrow range in all spaces is very expensive to install, operate, and maintain.

Typically, a single air handler conditions many spaces. In a single-zone constant volume system, the air handler supplies a pre-set amount of conditioned air to all spaces. Usually, it controls space conditions based on the temperature and RH of the mixed return air from all spaces. If air supply to all spaces is properly balanced and the temperature and RH load conditions in all spaces are the same, then this type of design will provide excellent control for all spaces.

In reality, for air handlers that supply a large number of spaces, there generally is some variance in temperature and RH load conditions from space to space. In order to compensate for this, either multiple air handlers are required, or a single air handler must supply each space or zone with differently treated supply air. This can be achieved with a multi-zoned unit. Multi-zoned systems are very common for temperature control since they are not very complex or difficult to install, depending on the design of the system and the number of zones involved. Humidity control is a different matter. A sophisticated multi-zone system cools the entire air volume based on the zone that requires the most cooling or dehumidification. Then, each zone has its own humidifier and reheat coil that operate on the basis of individual zone or room thermostats and humidistats.

While multi-zoned systems are capable of providing excellent control to individual spaces, the cost of installation and operation of such a system can be very high, depending on the number of zones involved, and especially when operated within narrow environmental parameters. Is the cost of such a system justifiable based on risk to collections? Rather than basing the interior RH range on a rigid and generic specification, a performance-based cost-benefit analysis can be carried out to determine if zoning is necessary and, if so, how many zones are required, both for human comfort conditions and for the preservation of collections.

The Collection

The introduction of an environmental control system can create a vicious circle whereby the system that was installed to protect museum collections can become a risk to the collections. The most obvious example of this is the risk to the building and collections from condensation, as discussed previously. Improper system operation and system failure can also result in risk to collections. There have been examples where sealed storage spaces with climate control equipment designed to preserve collections have experienced catastrophic mold outbreaks due to faulty equipment operation.

In general, environmental systems such as sophisticated multi-zoned air handlers designed for precision relative humidity control require a high level of maintenance. Complexity and maintenance further increases when a multi-zoned system is designed to provide different conditions in individual spaces. Various types of safety and redundancy features designed to protect collections introduce additional layers of complexity. There is a direct correlation between the level of complexity and the potential for failure. In sum, complex climate control systems are more prone to problems than simple, single-zoned systems. The risk to collections from failure of complex systems must be weighed against the risk of maintaining less precise humidity control with simpler systems.

An Evolving Standard

Avoidance of unintended consequences requires an understanding of the basis for standard museum RH specifications. In order to design and operate a climate control system, it is necessary to provide a specific temperature and relative humidity set point and range of acceptable fluctuation. The mechanical engineer or the automatic control system requires a specific temperature and RH value, not a discussion about what the collections can tolerate; therefore, the process encourages a prescriptive approach. From a performance perspective, temperature is based on the requirements of human comfort, whereas relative humidity is established based on collection needs. How is this performance-based RH value determined?

For most museums around the world that are designed to control RH, the selection of a humidity control point takes the environmental conditions of the region into account. For example, humid countries like Japan might select a range around 60% RH, whereas an extremely dry region like the southwestern part of the United States would select a value around 35% RH. A somewhat damp climate like the U.K. would typically be in the 50-55% range, whereas a climate that gets colder and drier in the winter such as the northeastern U. S. would try to maintain a 45-50% RH condition. In addition, many museums take seasonal conditions into account, operating at a higher temperature and RH level in the summer and a lower temperature and RH in the winter.

The acceptable range of temperature and relative humidity fluctuation is based on the concept of risk avoidance (Erhardt and Mecklenburg 1994). For hygroscopic materials that absorb and desorb moisture, stabilizing the RH surrounding the object based on an RH level that is appropriate to the object minimizes humidity-related damage. Since it is not practical to maintain an absolutely stable RH condition in an open public gallery, a certain variation in RH is inevitable. We understand that a small variation in RH is not a problem, whereas large RH fluctuations will place an object at great risk. Historically, the selection of an acceptable variation in RH has been determined by the capability of mechanical climate control systems. As system control has improved, the acceptable range of RH has narrowed (Brown and Rose 1996).

If a museum has a choice, most museums would prefer to practice a zero-tolerance for humidity-induced damage. Therefore, when a museum is designed or upgraded, it will prefer a system that can provide a tightly controlled RH environment. In the case of loans, the issue is not one of preference, but of contractual necessity. Many lenders require that borrowers maintain a specified RH range. Whether a lender actually maintains such a condition for the object, or whether the lent object actually requires such a tightly controlled environment is beside the point. If the agreement specifies such a requirement, it must be met. Therefore, for museums that cannot provide narrowly controlled RH conditions throughout their galleries, separate temporary exhibition spaces are often designed to meet the special RH specifications of borrowed objects.

Overall, the improvement in relative humidity control has had a very beneficial effect for the preservation of collections. Often, the selection of an operating RH range does take into account other considerations, especially regional climatic conditions. However, it is common practice on the part of collections preservation specialists to specify a relative humidity appropriate to collections needs without sufficient consideration of the wide variety of consequences for the building, the budget, and the ability of the climate control to maintain the specified conditions. Generally, this is not the fault of the collections specialist, or of any other individual. The problem lies with the planning process.

In order to begin the design process, basic information must be provided to the architects and engineers regarding space requirements, including target environmental conditions. Too often, the collections preservation specialist is asked to provide environmental requirements at the outset, but is not brought into detailed discussions about the full consequences of these requirements. As a result, it is not possible for the collections specialist to assess or weigh the relative costs, benefits, and risks of different options for environmental requirements within the context of other considerations. Without proper information on negative consequences, a collections preservation specialist will select a specification that minimizes risk to collections without regard for the impact on building or budget. Therefore, it is essential that the specialist who establishes environmental specifications for collections preservation be a more active participant from the very outset for those aspects of the design process where the complex relationship between building, budget, and collections requirements are determined. However, to attend such meetings is not enough. To be a successful advocate for the collection, the specialist needs to have some working knowledge of the decision-making process and of allied disciplines.

From Rigid Specifications to Flexible Guidelines

Rather than transforming museum environmental standards into a problem through the imposition of rigid specifications, it is better to use them as flexible guidelines for finding appropriate solutions. Unfortunately, rigid specifications may be necessary when faced either with an adversarial situation or if there is insufficient knowledge about how to adopt more flexible environmental standards that do not compromise the goal of collections preservation. Therefore, it is important to find ways to avoid unnecessary conflict. It is equally important for the collections preservation specialist to have a thorough knowledge of their own area of responsibility and a reasonable understanding of other specialties that impact the museum environment.

Conflict or Consensus

Improving environmental conditions in a museum is a complex task, typically involving a variety of specialists within the museum as well as others including architects, engineers, and contractors. If all specialists overemphasize their own highest priorities, there will assuredly be conflict. If each specialist takes into account everybody else's priorities and the need to balance competing interests, consensus can be achieved. Of course, differences of opinion about priorities will always exist. However, the greater the knowledge and appreciation about each other's specialties and responsibilities, the less will be the conflict.

The first step in avoiding unnecessary conflict is to identify all the players and define their roles and responsibilities. Within a museum, many staff positions have an impact on environmental issues and collection preservation. It ranges from board members who establish overall priorities and general budgetary parameters to facilities staff who maintain the climate control equipment. A partial list includes administrators, curators, designers, collections managers, registrars, conservators, art handlers, security, maintenance, and cleaning staff. A partial list of contracted specialists includes architects, engineers, exhibit designers and fabricators, facilities maintenance contractors, construction managers, the general contractor, and a large range of construction subcontractors.

It is necessary to define how each position can effect preservation and the environment. For in-house staff, training should be provided on the consequences, intended or not, of their decisions or activities. For contracted personnel, it is necessary to take into account preservation concerns at the outset of contract negotiations, and to carefully monitor ongoing performance.

The second step is to define the differences between priorities based on facts, requirements, guidelines, and preferences. While not an easy matter, how something is classified into one of these categories is important. For example, dew point (the temperature at which relative humidity will condense) is a fact that cannot be ignored. A specification such as building and fire code regulations must be followed, although some interpretation or variance is possible. A guideline provides a wider range of interpretation. The implementation of a preference is the most flexible of all.

In theory, priorities should be established based on their hierarchy as fact, requirement, guideline, or preference. In practice, things are never so clear. A preference sometimes starts life as a fact: for example, the budget. A budget is usually presented as an absolute fact. And yet, how quickly the budget can get modified due to an unforeseen emergency or when the authorities in charge find a way to modify the budget to accommodate a new priority that is of special interest. Conversely, a preference can quickly take on the inflexibility of a fact. For example, once a design feature such as a gallery skylight, incorporated as a preference rather than a necessity, is contracted for construction, it is very difficult and expensive to modify or eliminate even though it has yet to be built.

The Planning Process

The structure of the planning process for an architectural, design, or climate control project is essential to the success of the project. It should be an inclusive process, involving all key personnel, and one that permits good communication and exchange of ideas, concerns, and experiences at all stages. This is essential for the avoidance of unintended negative consequences. Unfortunately, this is often not the case.

For example, the architectural planning process for a large project tends to be quite formal and rigid. There are practical reasons for this. Architectural design is a complex affair involving many different specialties. Adherence to rigid schedules and formal communication protocols is required in order to control budget and schedule. Too many participants, all permitted to freely speak their mind, tends to slow down the decision making process. After decisions are arrived at and agreed to, changes become very difficult and expensive.

While the formality and rigidity of the architectural planning process may be essential from the perspective of budget and schedule, it has unintended consequences. The client must provide environmental specifications early in the process without the prior benefit of extensive discussions regarding the costs and benefits of these specifications. The contract design team develops a limited set of options for how the specifications can be met, generally without involving museum staff in the technical deliberations. Too often, the options that are presented to the client are overly simplistic and are intended to push the client into quickly agreeing on a single direction. This excludes the possibility of extensively exploring the costs and benefits of a larger range of design solutions or alternative specifications. It also limits informal communication and creative brainstorming among parties who do not normally interact on a regular basis. In sum, a rigid planning process will result in the need to establish and follow rigid specifications. A more open process encourages the exploration of flexible guidelines for an environmental control system that successfully balances the needs of collections preservation, along with other considerations such as cost of installation, operation and maintenance. And to accomplish this, the process needs to include the museum environmental preservation specialist in the earliest stages and throughout the development of the project.

Conflict Resolution

When there is not a strong commitment to resolve differences, conflict is inevitable. Assuming that all parties would like to find solutions that satisfy everybody, it is essential to analyze the underlying reasons that shape differences of opinion in order to find common ground for agreement. Too often, differences occur when specialists only focus on their own priorities and ignore or minimize the concerns of others. For example, if the curator, designer or architect insists on uncontrolled natural light without regard for light-sensitive materials on display while the collections preservation specialist insists on a specified low light level regardless of visual quality, there will be no possibility for a mutually acceptable solution.

Another point of conflict is the assumption that somebody is at fault if a specified condition is not achieved. The difficulty of achieving a specified environmental condition may be the result of a pre-existing condition. For example, if the building envelope is not designed to handle 50% RH in the winter due to the risk of condensation or if the humidification equipment does not have adequate capacity, it is not the fault of the facilities staff if they are unable or unwilling to operate the system at that high a level in cold weather.

Within the design process, there is the question of who is in charge and who ultimately resolves points of conflict. For an architectural project, this is a question that is very difficult to answer. On one level, it is the client who pays the bills. On another level, it is the architect. Contractual obligations and professional liability also play a role in defining ultimate authority. One thing is clear. Neither the client nor the architect is a neutral party in the design process. Conflict resolution requires that a single entity assume the responsibility of being in charge, preferably a neutral party who can weigh the merits of all sides in a conflict. Lacking such a neutral entity, it is difficult to find a well-balanced solution.

The best approach to avoiding conflict is knowledge and understanding. As previously stated, knowledge of the performance basis for environmental specifications provides more flexibility for finding appropriate solutions. Understanding the responsibilities, concerns, and constraints of other specialists provides a degree of empathy for their perspective. If the other specialists can reciprocate in kind, consensus can be achieved.

Educating the Museum Collections Preservation Specialist

Who needs to be educated about the museum environment? To some extent, the wide variety of museum personnel and outside specialists who have an impact on the design and maintenance of an appropriate environment for collections preservation all need some level of training. It is not an easy matter to require this diverse group to improve their level of knowledge and understanding, although professional publications and workshops attempt to address this need. More of this type of activity should be encouraged.

Another deficiency is the lack of collections preservation specialists who possess adequate environmental training. Traditionally, the conservation profession has taken the lead in developing environmental standards. Registrars and collections managers, in conjunction with conservators, have been important preservation and environmental advocates. While each group has some familiarity with the museum environment, there is a lack of real expertise on the subject. Clearly, it is impossible for all conservators, collections managers, and registrars to become experts on the museum environment. The subject is too broad and too complex. However, a core curriculum, providing more depth than the current approach that emphasizes rote numbers and prescriptive formulas, should be developed and taught to these collections specialists.

At a higher level, a more detailed curriculum should be developed for those individuals within the institution who will assume a large responsibility for environmental preservation issues. Inevitably, the level of training will vary with the degree of interest and responsibility of the position. To address this, training options at a variety of levels should be developed. Within training programs, some specialization beyond a basic introductory course should be offered. Short-term workshops and extended mid-career training opportunities also should be developed. The goal is not to train a specialist whose sole responsibility is the environment. Rather, it is to supplement the capability of collections specialists who already carry the responsibility for the preservation of their collections so that they can make informed decisions and recommendations on environmental matters.

Defining Roles and Required Knowledge

A collections preservation specialist has three distinct roles that define the type of knowledge and skills required when dealing with issues of climate control.

The first role is as a team member in the design and construction process for renovation or new museum projects. Here, the preservation specialist must play an active role in evaluating the costs and benefits of various options for environmental control. To do this, it is essential to have some understanding about the functions, responsibilities, and pertinent concepts of all specialists who have a major role to play regarding environmental systems. How much knowledge is necessary to fulfill this task? Of course it is impossible to know everything about everybody else's specialty. To some extent, the required level of knowledge required for successful interaction should be defined, at least in part, by the specialists themselves since they have the best appreciation of what the client must know if the client insists on being an active participant in the design process.

As a member of the design team, there is a broad area of complementary knowledge with which the preservation specialist needs to be familiar. This is the kind of information that overlaps with the specialist's area of expertise, but is unique for museums and should be determined by the museum specialist. A good example is filtration for climate control systems. An engineer can describe basic levels of filtration that are available. Although an engineer will be familiar with the physical requirements for accommodating the different types of filtration systems, they should not determine requirements for museum collections. Therefore, the collections preservation specialist has to understand the full implications of each option and should participate in the final selection. Although it is always desirable to have the highest grade of particulate filtration and some capability for filtration of gaseous pollutants, this level of filtration comes at a cost. It may be difficult or impossible to retrofit existing systems with such upgrades. And the installation and long-term maintenance of high performance systems can be very expensive. The engineer can advise the museum about these considerations, but should never tell the museum what is best for them. It must be the museum's decision, based on a full understanding of the consequences of each option.

While it is important to have complementary and overlapping knowledge, the collections preservation specialist should not be in competition with other specialists. If a preservation specialist has to tell a mechanical engineer how to size or select a chiller, either the preservation specialist is micromanaging the project, or the museum has hired the wrong engineer. Sometimes, it is difficult to tell which is correct. It is important to be cautious about exercising too much authority based on too little knowledge; but, if the preservation specialist has serious concerns about aspects of the engineer's design, these concerns should not be ignored and should be brought to the engineer's attention. If the response is not satisfactory, a second opinion should be sought.

The second role deals with smaller scale projects. With regard to climate control, the responsibility of the collections preservation specialist can extend beyond providing environmental specifications. Often, these projects are too small to involve an architect or mechanical engineer. Instead, a contractor is brought in to design and install climate control equipment. Without access to an experienced mechanical engineer, a great deal of responsibility for selecting or approving appropriate equipment is shared by in-house staff, including facilities and the preservation specialist. Therefore, some level of knowledge about the suitability of proposed solutions is required.

The third role deals with responsibilities that are unique to the preservation specialist. This includes such areas as environmental monitoring, microclimate maintenance, and materials evaluation for suitability in showcase applications.

Risk Management

The first step in a training program in preventive conservation and environmental protection of museum collections is to develop a skill in risk management. Risk assessment and risk management are essential tools for balancing collection preservation needs against other competing interests (Waller 1994, 1995, 2003). In its most obvious application, it is a method for determining best allocation of limited financial resources. But it can also be used to resolve conflicting issues, such as the playoff between preservation requirements for low light levels and visual needs of the public.

Risk management requires technical knowledge about the collections and the factors that cause damage. Risk assessment should not be a black and white statement about risk. Properly done, an assessment should deal with the complex world of partial solutions. For example, if it is not possible to fully stabilize relative humidity to the optimum level to eliminate risk, an assessment should provide information on the degree of risk reduction due to some level of improvement in environmental conditions.

Collections-based knowledge dealing with *what* modifications are required is only half of the risk management equation. The other half involves knowledge of *how* to modify conditions. With regard to the museum environment, it is necessary to understand building and climate control systems at both the macro- and micro-environmental level. A full risk management program must assess the cost and benefit of a variety of environmental control options on the preservation of collections, as well as the impact on the building, the climate control systems, and the budget. It is essential to be aware of unintended consequences at all levels. For example, a requirement for increasing space relative humidity must consider such factors as the design of the building envelope, risk of condensation, and limitations with existing mechanical systems. Lower priority risks may assume a higher priority due to the ease of implementation. Partial solutions that reduce risk to collections may be preferable to *ideal* solutions that eliminate risk, once the potentially negative consequences of the ideal solution to the building, existing systems, and the budget are taken into account.

Cost-Benefit Analysis: Simplifying the Equation

Risk assessment provides a methodology for weighing the costs and benefits of various options for upgrading the museum environment, but it requires familiarity with many areas of knowledge beyond the environmental impact on collections. But, it is unrealistic for a collections manager or conservator, even with some special training and specialization in environmental technology, to have enough expertise in the areas of architecture, mechanical engineering, and lighting to make such cost-benefit decisions. In fact, no single individual, either among contracted specialists or in-house museum staff, has this total level of expertise. The knowledge and capacity to make informed cost-benefit decisions resides with the entire group.

Unfortunately, most design teams are not organized to do collections-oriented cost-benefit analysis, even if the primary purpose of the project is to upgrade mechanical systems to improve the environment for collections. The museum provides an environmental specification at the outset of the process. At the end of the programming phase, and throughout the schematic phase, the design team assesses the feasibility and cost of meeting these specifications. All too often, detailed technical discussions exclude most if not all museum personnel, and especially the museum's collections preservation specialist. Complex considerations and decisions are distilled into a limited number of options outlining how specifications can be achieved or how specifications need to be modified, either to reduce costs or due to other considerations such as building and equipment limitations. The advantage of this process is that it reduces an enormous number of technical and cost considerations into a limited set of options, and simplifies the decision making process for the museum. The disadvantage is that it excludes alternative options that might be more appropriate if the team more fully understood the museum's full range of concerns and priorities and particularly, the flexibility of the museum's environmental specifications. A meaningful cost-benefit analysis cannot be carried out on an oversimplified set of options, arrived at without including key museum personnel in the actual development of the options.

What level of knowledge does the museum's preservation specialist require, and to what extent does this specialist need to participate in the design process? As previously stated, it is impossible to know everything about everybody else's specialty. Nor is it useful or practical for the museum specialist to attend every meeting and discussion. The preservation specialist should know enough to ask the right question, and to participate at key points in the process when these questions need to be asked. And what are the right questions? Mostly, they are about break points or *quantum leaps* in design and cost.

A quantum leap differentiates a series of small or incremental steps or decisions from a single, abrupt change. The decision-making process is composed of an enormous multitude of incremental decisions, best determined by the technical experts. But, there are also key break point decisions that will result in clear, discrete quantum leaps in terms of project costs and building performance. These are the decision points that need to involve the museum's preservation specialist as well as other appropriate museum representatives.

Here are some examples of quantum leap decisions:

Example 1—A small museum is about to install a new electric humidifier. Normally, sizing the humidifier is a technical decision, based on load calculations carried out by the engineer to meet RH specifications required by the museum. Generally, a slightly oversized humidifier is selected to ensure adequate capacity, since the cost of increased capacity is incremental and has little impact on overall project costs. However, what should be done if the museum has only enough electrical capacity to operate a humidifier that is somewhat undersized? Here, the issue is not the small incremental cost of a larger capacity humidifier, but the quantum leap in cost of installing additional electrical service. Rather than leaving it up to the engineer to determine whether the large increase in cost is justified or not, the collections preservation specialist needs to be a part of the decision and to know the right questions to ask. For example, will the smaller sized unit provide adequate performance for most of the year? How low will the humidity go during very cold weather? Can a somewhat higher interior RH be maintained by reducing outside air and interior temperature conditions by a few degrees? Should a lower RH set point be established? Answers to these types of questions provide the kind of information necessary to make optimum object-oriented cost-benefit decisions.

Example 2—A museum is planning a major renovation. It has an existing air handler and duct distribution system that supplies both collections and non-collections areas. The unit can be upgraded with incremental modifications that will improve conditions, but it will not be able to provide the level of control required to meet specified RH conditions in collection areas throughout the year. Replacing the air handler and existing ductwork represents an enormous jump in project cost. This is another example of a quantum leap decision point. The preservation specialist needs to ask a series of questions about the consequences of the decision to modify or replace equipment. What exactly are the performance shortcomings of an upgraded unit compared with a new system? Where is the point at which upgrades become so expensive that it is better to invest in a new system? What is the service life of the existing system, and does it need replacement for other reasons?

In the above examples, the collections preservation specialist does not have to know how to do humidity load calculations, climate control system evaluation, or cost estimation. At a minimum, it is necessary to know enough to recognize and discuss these quantum leap points, especially if the design team does not identify them. Focusing on these major quantum points rather than on an infinite number of incremental decisions clarifies the minimum degree of involvement, experience, and the amount of information that a preservation specialist must bring to the decision-making process. In terms of risk management, these solution-oriented break points define a limited number of variables that can be used to simplify the equation used to balance environmental benefits or risk to collections versus costs to the overall institution.

Specialized Skills

In addition to the ability to understand and communicate with other specialists, collections preservation specialists need to develop skills in areas for which they have special responsibilities. The required skills will vary with each type of collecting institution, but typically involves knowledge of environmental monitoring and microclimates.

Environmental monitoring involves a great deal more than changing hygrothermograph charts or downloading data loggers. It requires a thorough understanding of monitoring equipment, including differences in types and quality of instruments available, calibration procedures, and how they should be handled and maintained. Beyond the normal range of equipment, there is a wide range of moderately priced instruments for monitoring other parameters that are not familiar to most museum specialists, such as air movement, moisture in materials, surface temperature, and exhibition case leakage. It is also important to know how the data should be used. Monitoring is more than just a regulatory function, used to confirm that environmental conditions are within an acceptable range. Monitoring is an important diagnostic tool that can be used to understand equipment malfunctions, or to develop an improved environmental control strategy.

When an object is placed in a sealed exhibit case or storage unit, a microclimate is created. Because of a low rate of air exchange, the interior microclimate can control the level of relative humidity to a different level than that of surrounding conditions, either passively with silica gel, or actively with specially designed equipment. Most exhibit case designers and fabricators do not have an adequate understanding of the technologies involved in implementing and maintaining a micro-controlled environment. Another byproduct of a low air exchange rate within a sealed unit is the risk of damage to collections from entrapment of pollutants. Many materials used within the interior of exhibit cases and storage units will give off gasses that are harmful to museum collections. It is important to test and control the type of materials used in case construction. Again, these are other areas of knowledge and responsibility that are unique to the preservation specialist.

The Curriculum

Although this article deals with light, temperature, relative humidity, and pollution, these are only some of the risk factors that effect museum collections. Fire, vandalism, pests, natural disasters, and physical damage due to poor handling are some other examples of risk factors. Any introductory curriculum that deals with the museum environment should be taught within the context of risk management.

An environmental curriculum must focus on process and solutions, not just the identification of problems. It requires an engineering-based knowledge of how systems work, not just a scientific knowledge of deterioration. There is a tendency for training programs to prefer prescriptive formulas that can be easily taught and tested. There must be a shift toward a more performance-based approach.

The museum environment is a complex subject that can take a lifetime to fully master. However, the principle concepts and information can be condensed into a short-term course. The goal of an environmental curriculum is to select the key information that a preservation specialist must know, so that it can be taught within the context of a preventive conservation program. The outline below provides some suggestions for the kind of subjects and information that should be included in such a curriculum:

Collections-Based Subjects

- Basic information on light, temperature, humidity, and air pollution—this includes information on how each can damage collections, how each is monitored, and how each is controlled.
- Performance guidelines for the control of environmental factors: Understand how guidelines can be converted into specifications that make sense for a specific application as part of the design process.

Process-Based Subjects

- Introduction to the allied professions involved in the design process—this includes the architect, exhibit designer, lighting designer, mechanical engineer, and construction team. The course should describe their responsibilities, areas of knowledge, key concepts, and specialized vocabulary that must be understood by the museum preservation specialist. As part of the coursework, specialists in these professions should be brought in as guest lecturers.
- Presentation of inner workings of the design process from the initial pro-

gramming stage, schematic, design development, construction documents, bidding and negotiation, through construction and commissioning.

- Learn to read architectural drawings: Focus on what is important to understand relative to the task of environmental control.
- Concentration on special topics that have a major impact on collections preservation, for example:

—The building envelope.

—The use of natural light in exhibition galleries.

—Climate control equipment design and operation.

- Develop expertise in areas of complementary knowledge that supplements the expertise of other specialists, for example:

—Particulate and gas filter selection for climate control systems.

—Ultraviolet filtration for light sources.

Solution-Based Subjects

- Cost-benefit analysis utilizing a quantum point method to evaluate system design options, for example:

—Precision control with multi-zoned systems versus moderate control with single-zoned systems.

—Equipment modification or replacement.

- Gain practical experience with certain in-house functions that affect collections preservation, for example:

—Exhibition lighting.

—Operation of climate control equipment.

- Environmental monitoring, for example:

—What is the purpose of monitoring?

—How should data be utilized?

—What type of monitoring equipment is available?

- Microclimate techniques:

—Methods for the control relative humidity in sealed microenvironments.

—Expertise in evaluating and testing case materials.

Conclusions

The museum environment is a complex subject that cannot be reduced to a simple set of specifications without a risk of unintended and adverse consequences, both to the collection and to the overall institution. The solution for avoiding bad decisions about the museum environment is to improve communication and collaboration among and between in-house and contracted specialists. In theory, this should be an easily achievable goal. In reality, it is difficult to realize, often in spite of the best intentions of the project participants. A number of suggestions for improving communication and collaboration have been discussed and many more could be added. The task ahead is to implement these improvements. Among the recommendations described, one in particular has been singled out as the subject of the second half of the article—the training of a museum collections preservation specialist.

Collections management and conservation programs need to provide more thorough training in preventive conservation in general and environmental topics in particular, expanding beyond their traditional focus on agents of deterioration. A greater awareness of how to participate in decision-making processes, and an engineering-based understanding of the technologies involved in environmental control is also essential. The subject of the museum environment should be introduced within the overall context of risk management, since environmental risks are a subset of a larger group of risks, all of which must be taken into account.

Throughout the world, there are very few museums that have a full-time position for a collections specialist whose sole responsibility is the museum environment. In most instances, a full-time position may not be necessary. But there is an urgent need for museums to hire specialists in collections management or conservation who have extensive environmental training, and are given the time and resources to focus on the environment as an essential part of their professional responsibility.

Acknowledgment

This article is dedicated to Carolyn Rose, a pioneer in the field of preventive conservation.

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