Practical Approaches to Environmental Control at the Shelburne Museum

Richard L. Kerschner

λ Museum Grounds Spring Winter

In 1983, I was hired to establish a conservation department at the Shelburne Museum, a collection of fine and folk art and Americana exhibited in 27 buildings on 40 acres in northwestern Vermont. Although founder Electra Havemeyer Webb was aware of collections preservation issues such as they were known when she was building the Museum in the 1940's and 50's, little attention was paid to preservation of the collection after her death in 1960 as her son led the Museum in constructing new exhibit buildings and mounting new permanent exhibits for the next 20 years.

When I came to Shelburne Museum directly from the Cooperstown Graduate Program, little did I realize that I had spent the past three years learning the basics of barely half of what was required to successfully preserve Shelburne Museum's collection of 150,000 artifacts. Since conservation graduate training at that time focused mainly on artifact treatment, as a new conservator, I was gaining confidence performing conservation treatments on artifacts made of a variety of materials. However, I soon realized that I had to not only stabilize and restore deteriorating objects, but I also had to do something to slow their deterioration and keep them from falling apart. In taking the job at Shelburne, I had stumbled, or perhaps leaped, into the emerging field of preventive conservation.

Over the past 25 years, I have performed few conservation treatments. Nearly all of my efforts have been directed toward devising, developing, implementing, evaluating, and promoting practical low-cost preventive conservation measures such as relative humidity control and exhibit lighting improvements.

λ General Store GS Interior Shaker Shed Tool Wall

Twenty five years ago, 68ºF, + or – 2 degrees, and 50% relative humidity, + or – 3%, were generally accepted as the required temperature and humidity levels for the long-term preservation of collections. λ As I became more familiar with Shelburne's varied collections and the buildings that housed them, I came to realize that such restrictive standards were not only unreasonable for buildings that included a covered bridge and several barns, but probably unnecessary for the preservation of most of our artifacts. λ As I examined collections in the various exhibition and storage buildings, I found that most of the 70 to 150 year old artifacts were in good condition, even though they had experienced minimal environmental control and been repeatedly exposed to seasonal temperature extremes of 0º to 90ºF and relative humidity extremes of 10% to 95%. Those artifacts in poor condition had been damaged by extreme conditions in attics that were too hot, basements that were too wet, or buildings that were too dry because they were heated but not humidified during cold weather.

λ Moldy Print **Cracked Cigar Store Figure**

I realized that even though we may not be able to achieve "ideal" museum environments, we could significantly improve conditions by reducing humidity extremes surrounding our artifacts. By keeping relative humidity below 65% in the summer, we could avoid mold growth and prevent significant swelling of organic materials. λ By keeping humidity above 35% in the winter, we could avoid drying out our collections. Research indicated that our Canadian neighbors had been following these wider RH standards for at least a decade. Ten years later in the early 1990's, scientists at the Smithsonian's Conservation Analytical Lab researching the response of various materials to changes in relative humidity would determine that these broader RH standards were indeed safe for the large majority of historic artifacts. In addition, our artifacts had been "proofed" by high and low humidity extremes for many years. The worst damage had already been done. By narrowing the range of humidity extremes artifacts would experience in the future, we could insure that no new damage would occur even if the new conditions were not ideal.

Adopting broader humidity standards opened up additional possibilities for practical environmental control methods that fell well short of complete control, while still improving environmental conditions and eliminating humidity extremes that cause the most artifact damage.

λ Dutton House **Inside**

One big question still remained. What kind of environments could our various buildings support? We certainly did not want to create environments to preserve our artifacts only to destroy the buildings that house them. Only four collections buildings had been built as galleries, and even they had little insulation and no vapor barriers. We knew that humidity introduced into such buildings in winter could result in serious building degradation. Fortunately, Ernest Conrad had just established Landmark Facilities Group to specialize in improving museum environments and he was challenged by the question of what type of environmental improvements various building structures could safely support. During a survey of Shelburne's buildings, he devised a building classification system that is now included in the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (better know as ASHRAE) Applications Handbook, Chapter 21, that addresses environmental control in museums, libraries and archives.

> **λ Covered Bridge**
>
> **Class 1** buildings are open structures such as covered bridges or open sheds. These structures have little potential for environmental improvements although they sometimes protect important artifacts from the harsh elements.
>
> **Horseshoe Barn**
>
> **Class 2** buildings are sheathed post and beam structures such as barns. The only reasonable climate improvement for such buildings is ventilation to reduce heat and moisture accumulation.

λ Prentis House

Class 3 buildings are wood structures with framed and sided walls and single glazed windows, or un-insulated masonry structures, your basic historic house. In these structures, one can use conservation heating to reduce high humidity levels in cool weather, and employ conservation ventilation to reduce humidity in the summer.

λ Dorset House

Class 4 buildings are tightly constructed wooden structures with composite plastered walls and storm windows, or heavy masonry structures, typical of high quality historic houses. These buildings can support conservation heating in the spring and fall, low level heating with some humidification in the winter, and cooling and reheating for dehumidification in the summer.

λ Pleissner

Class 5 buildings are new-built structures with insulated walls with vapor barriers and double glazed windows. These buildings can support complete HVAC systems with winter comfort heating and humidification, and summer cooling and reheating for dehumidification.

λ Library

Class 6 structures are rooms-within-a-room, double wall construction with insulated and sealed walls, such as storage vaults specially built to support precision controlled heating, cooling, and humidity control systems.

Armed with the knowledge of what our collections could withstand and what our buildings could safely support, we were ready to design practical systems to improve collection environments. In 1992, Shelburne Museum received a grant from the National Endowment for the Humanities, Division of Preservation and Access, to support a $1.4 million project to design and install practical climate control systems in 27 of our collection buildings.

λ Spray Truck

It would be foolish to design and install mechanical systems to filter out dust or reduce moisture in a building without first taking steps to reduce such problems at the source. Such practical building and site improvements can range from simple to complex, but even the most complex practical improvements cost considerably less than installing mechanical climate control systems and their continuing operating costs are very low.

Our first action was reducing dust from our dirt roads at the source. Although paving had been considered, not only were the initial paving cost and continuing maintenance costs quite high, but macadam roads would not be aesthetically pleasing in our village setting. Vermont still has many dirt roads, and we found that the State of Vermont sprayed their dirt roads with a calcium chloride solution every Spring to reduce dust. The hygroscopic calcium chloride draws moisture from the air to keep the road surface slightly damp. It takes a contractor only a few hours to cover all the roads and parking lots at the entire 40 acre museum and costs $5000 for a full application. However, we find that one application is effective for two or three years, so annual costs for dust control average around $2000, which we probably save in filter replacement and housekeeping costs.

λ Gutters Storm Drains

λ A more complicated problem was moving water away from the buildings by installing roof gutters and improving surface drainage. Roof gutters are easy and inexpensive to install, relatively unobtrusive, and easily reversible. However, they have to be thoughtfully designed and properly installed, they require regular maintenance to remove debris, and they are often a non-original addition to a historic building. λ Improving surface drainage can be as simple as sloping the ground away from the foundation or as complex as installing an engineered exterior surface water drainage system as pictured on the right. A surface water drainage system was recently completed on this building because water continued to enter the basement even after a complete roof gutter system was installed. Surface drainage systems are invisible and do not require as frequent maintenance as roof gutters, but they must be carefully designed and are labor intensive and expensive to install. λ It does no good to channel water from the roof into a gutter system if it is simply discharged near the building foundation to seep back into the ground and basements. To move water away from the buildings and off the grounds, our aging storm drain system had to be improved and expanded.

λ Sealing

Sealing and insulating are the most cost-effective methods to reduce energy costs in historic buildings. Because sealing and insulating decrease interior **extremes** in temperature and humidity, they are crucial actions if you are planning to install any type of system or even no system at all. A blower door test is essential in identifying air leaks throughout the building. By putting the building interior under a negative pressure, air leaks around window and doors, through holes between floors, and even through electrical outlets are exaggerated so they can be easily identified and marked for sealing. A baseline pressure is measured and a second test and reading after the leaks have been sealed can accurately assess how effective the sealing process has been. Energy and cost savings can be easily quantified. Because Shelburne Museum is one of the larger energy users in the state, Efficiency Vermont, the State energy efficiency utility, conducts these tests free of charge and provides cash incentives to insulate our buildings. The picture on the right shows just how much fun this work can be!

λ Interior Storm Windows

Poorly sealed windows are often the leakiest areas of a historic building. Interior storm windows are one of the best and most economical passive environmental improvement measures you can make in a historic house because they solve several problems. If properly installed with a gasket, they seal leaky old windows and prevent moisture from condensing on the inside surfaces of historic single-pane windows. They raise the R-value of the windows, reducing heat loss through the glass. Proper glazing materials block harmful UV radiation and reduce light levels in the room. They can also improve building security, making break-in through a window much more difficult if not impossible. They can often be secured in place using original window molding as seen on the left, but even if they need to be surface mounted as shown on the right, the frames can be painted so they are nearly invisible.

λ I recommend using tinted polycarbonate (Lexan) or acrylic (Plexiglas) for interior storm windows. We usually prefer polycarbonate because it inherently filters out 93% of the UV radiation, whereas special tinted UV filtering acrylic is twice the cost. Polycarbonate is also more difficult to penetrate in areas where break-ins are a concern. However, Acrylic is harder than polycarbonate and more scratch resistant, so it may retain its clarity better over the long term. Warm bronze tinting is preferable to cool gray tinting.

This building, built in 1960 to house our Impressionist paintings in their room settings, has a complete HVAC system with humidifiers. Electric perimeter heaters were built in underneath the windows to keep the glass warm during cold weather to prevent condensation on the inside of the windows. Interior storm windows eliminated the need for perimeter heaters on 23 windows, saving a significant amount of money.

λ Although elimination of UV radiation alone will reduce fading by around 75%, tinting is important because visible light does fade artifacts. Several different shades of tinting are shown on a large window in our conservation exhibit. The center bottom window is glazed with untinted UV filtering acrylic sheet. The 60% tinting on the center four windows will hardly be noticed by visitors and reduces glare nicely. The 80% tint on the top center windows is just a bit darker. We now use 90% tinting in most of our historic building windows as shown on entire left window. Purchasing 90% tinted acrylic is the most economical way to protect collections from damage due to UV radiation and light. One saves the cost of buying UV filtering acrylic because 90% of all radiation, visible and UV, will be blocked. This can reduce the cost of an average sized interior storm window from $350 to $125. Surprisingly, 90% tinting does not significantly deter viewing out of the windows. It does significantly reduce the light entering the building so a supplemental lighting system will be required inside the rooms. Since blocking all light is even better than reducing light levels, the day after we close for the season, room-darkening shades are drawn or light-blocking Foamcore panels are placed in every window and remain in place until we re-open 6 months later.

λ Insulation

Insulating a building seals it and reduces heat loss. Densely packed cellulose insulation is well suited for blowing into attic spaces and historic building walls. It increases the moisture buffering capability of the building and stops air and moisture movement in the wall cavities. For this reason, insulating with densely packed cellulose does not require that the inside walls or ceiling be retrofitted to include a vapor barrier. λ Although fiberglass insulation is sometimes less expensive and easier to install, it has a lower R value per inch (3.2) than densely packed cellulose (3.5). Because fiberglass does not stop air and moisture movement through the walls, the installation of a vapor barrier is required when using fiberglass insulation, a very difficult task in a historic structure.

λ Recent studies indicate that up to 25% of the building's heat loss is through basement walls. This loss can be significantly reduced by spraying the walls with 2 inches of polyurethane closed-cell foam, especially over the sill areas where wood timbers rest on the foundation. This foam has a very high R value (6.5 per inch) and costs about $2 a square foot for a 2" thick application. Another significant advantage is that it can be sprayed over pipes, wires, and wood to completely seal openings between the foundation and the wooden sill beams as well as penetrations between floors as shown on the left. When used to seal the walls of a crawl space, the foam can also be applied to tightly seal the plastic vapor barrier covering the dirt floor to the base of the wall.

λ Since polyurethane foam seals complicated and different sized openings so well, it can be used with cellulose insulation to tightly seal and insulate an attic space. The key to a good insulation job is to remove everything from the space to be insulated so that all openings can be easily identified and accessed. Mark leaks identified during the blower door tests with tape for special attention by the insulators. Your State energy efficiency program can recommend the best type of insulation to use and provide a list of qualified contractors, and may offer cash incentives. Solicit bids from several insulation professionals. Bids can vary considerably and the lowest bid is not necessarily the best. Choose a contractor that has experience insulating historic buildings and is very detailed oriented. Since most of the cost of insulating is for labor, we found that the bids were lower if contractors viewed the space after it was completely emptied, probably because empty spaces are easier to access and work in, especially when using spray guns for foam and large hoses to deliver the cellulose insulation.

λ SM Diagram

A simple drawing in Stefan Michalski's chapter on "Incorrect Relative Humidity" on the Canadian Conservation Institute's online Conservation Resource Center helps summarize some of these simple preventive actions. (explain drawing)

This brings home the concept that several simple actions can combine to have a very significant effect on improving collection environments, greatly extending the useful life of historic artifacts.

λ Attic Fan **Basement Fan** **RH Sensor**

Conservation Ventilation

The simplest of mechanical systems used to mitigate temperature and relative humidity extremes is conservation ventilation. We installed conservation ventilation in nine of our Class 2 barn-like structures since it was apparent that during the summer, heat and humidity built up inside many of our historic structures, especially on the upper levels. λ The key to conservation ventilation is using a humidistat to control the fans rather than a thermostat. When it is cooler and drier outside than inside, λ the fans are activated and the hot moist interior air is replaced by cooler, drier outside air. Our consulting engineer calculated that it would require about 7 air changes an hour to effectively exhaust this hot, humid air. However, simply installing and operating an attic fan would solve one problem but create another, introducing seven times as much dust into the collections areas. λ We solved this problem by not only exhausting air through the attic, but by also using fans to draw air into the basement or first floor of the building through filters that trap the dust. The fans forcing air into the building are sized larger than the exhaust fans so that the entire building is under a slight overpressure, thereby discouraging dust from entering when visitors enter the buildings. A study of Shelburne's systems conducted by the Getty Conservation Institute concluded that conservation ventilation lowers building humidity levels by about 10%. In addition, moving the air prevents mold growth even when the humidity is above 70%.

λ Furnace Boiler RH Sensor

Conservation Heating

To reduce humidity in our Class 3 historic house structures we use both conservation ventilation and conservation heating, sustainable climate control methods that work with nature instead of against nature. λ Conservation heating is the practice of controlling the relative humidity in a building by adding or withholding heat. It is possible to dry out a cool, damp building simply by introducing heat. Conversely, withholding heat and allowing a building to cool during cold weather will keep the relative humidity high enough to be safe for the artifacts even during cold Vermont winters. λ In Vermont's temperate climate, conservation heating keeps the humidity below 55% in collection buildings during the fall, winter, and spring. λ As with conservation ventilation, a humidistat activates the climate control equipment, in this case a furnace or boiler. Conservation heating is quite efficient since for every 1ºF the temperature increases, the relative humidity drops 1.4%. Only small amounts of heat are required to reduce relative humidity to 55% even during the damp rainy seasons. During the winter, this is a very economical method of humidity control since the heat is seldom called on. Once the outdoor temperature drops below freezing, the relative humidity remains well below 55% even in our cold buildings. Although the buildings are uncomfortably cold, this method works very well for Shelburne Museum since we are closed from November through April.

λ Prentis House Interior Painting Portrait Storage

Cold temperatures do not harm artifacts usually found in historic house museums, as long as items such as furniture are not moved or handled roughly when they are very cold. In fact, the low temperatures reduce the rate of deterioration caused by chemical reactions in wood, paper, textiles, photographs, and other organic materials. λ One exception might be paintings on canvas, especially acrylic paintings. Since some research has shown that cold temperatures can cause the paint and ground to crack, we remove paintings from our historic houses to a warmer, humidified storage building for the cold winter months.

For a thorough understanding of just how beneficial low temperatures are for preserving artifacts, spend an hour or two reading and understanding Stefan Michalski's online chapter on "Incorrect Temperature." λ This chart from that chapter gives an idea of the magnitude of the increase in the life of an artifact by simply reducing temperatures (explain table). Even if the temperature in decreased for only 6 months a year every year, the preservation benefit is huge. For those institutions that are open year-round, temperatures could at least be reduced to 50°F in storage areas, greatly reducing deterioration of artifacts while saving energy and money. You get the idea.

λ Quotes

So what are the drawbacks of reducing temperature? Aside from uncomfortable conditions for people, apparently very few. Stefan Michalski states the following: "Overall, low temperature is beneficial to collections, but polymeric materials, such as paints, become more brittle and fragile. Fortunately, careful handling mitigates most of the risk."

And what is meant by careful handling? (read quote) Essentially, don't hit or drop paintings when they are cold. We extend this caution to all organic materials. For example, we try to avoid moving furniture when it is very cold since the glue could be brittle. We avoid any handling our quilts when they are cold because the fibers are colder, drier, and more brittle. These are minor compromises for doubling, quadrupling, or increasing by ten-fold the life of our artifacts and saving significant money on energy costs.

λ Hat and Fragrance Unit Quilts

Modified Use of Conventional HVAC Systems

Conventional HVAC systems can be used to improve collections environments in Class 3 and 4 buildings if they are operated properly. We have modified the operation of the HVAC system in our Hat and Fragrance Textile Gallery, a Class 3 structure where we exhibit a rotating selection of Shelburne Museum's celebrated quilts and coverlet collection. High summer relative humidity levels are reduced by the conventional means of using a cooling coil to super-cool the air to condense out the moisture then reheating the air to reduce relative humidity before the conditioned air is discharged into the galleries. However, because this barn-like structure is poorly insulated and has no vapor barrier in the walls, we do not introduce any humidity into this building during the winter, choosing instead to allow the building to go cold to keep the relative humidity above 35%. Not only does withholding heat maintain a safe humidity level and save us money, but allowing temperatures to drop as low as 0ºF also slows chemical deterioration and discourages insect activity in the textiles housed in this gallery.

λ Stagecoach Inn Humidifier

The Stagecoach Inn is a good example of a Class 4 structure with a complete HVAC system that includes low-level humidification in the winter. This building has plaster walls filled with old vermiculite or Perlite insulation (R 2.7) and tight interior storm windows. Care must be taken to minimize the amount of moisture introduced into a structure with limited vapor retarding ability to prevent moisture from condensing inside cold walls and rotting the structure. During the winter, the building temperature is reduced to 55ºF and a steam humidifier is used to introduce a minimum amount of moisture and maintain the relative humidity between 35 and 40%. At these low temperatures, it is important to keep the air moving continuously, even when the heat is not on, to ensure that there are no cold, isolated interior walls where condensation could occur. Our engineers advised that moisture should not be introduced into buildings at a temperature below 55ºF because at lower temperatures, even small increases in air moisture content can result in high relative humidity levels and increase the risk of condensation on cold interior surfaces.

λ PEM Monitor **Moisture on Windows**

Humidified Class 4 structures must be carefully monitored during cold weather. By observing condensation on the inside of windows while monitoring relative humidity levels inside wall cavities, we have devised a good empirical indicator of a safe moisture level for our structures. Some haze on the inside of the windows is a warning that moisture is beginning to condense on the coldest surfaces in the building. If drops of water begin to run down the windowpane, the humidity is too high and must be reduced.

λ From experience we have found that if the outside temperature is above 32ºF, we can safely humidify the building to 45%. As the outside temperature drops from 32ºF to 20ºF we drop the relative humidity to 40%. Between 20°F and 10ºF, the relative humidity set-point is gradually reduced to a minimum of 35% by our building digital control system.

λ Digital Controller **CC Computer**

Digital Controls and Monitoring

None of the environmental control methods discussed could be practically employed without the use of digital controls. Shelburne's 1991 NEH grant provided funds to connect all 27 collections buildings through underground wiring and to purchase and install digital controls, in our case, the Johnson Control Metasys building management system. Although all the systems can be monitored and adjusted from a central computer, actual control of the various building systems is decentralized to 12 digital control panels, like the one on the left, distributed throughout the campus. If communications with the central computer are disrupted, these control panels seamlessly continue to operate the systems in the building based on the most recent outdoor temperature and humidity information received from the computer. For a stand-alone building, the digital controller is all that is required.

Using digital controls, one can combine the various practical climate control methods. For example, while the Museum is open in the spring and fall, conservation heating can be used in our buildings with conventional HVAC systems to save on dehumidification costs. The conventional method of controlling humidity would be to set the temperature at 70°F and use lots of energy to run cooling and reheat at the same time to reduce humidity on cool damp days, and a steam humidifier to increase humidity on dry days. Instead, the heat is programmed to drift between 65°F and 74°F based on the humidity level in the building. During cool rainy weather, the building will be as warm as 74°F if the heat is activated to reduce inside humidity. During cool dry weather, the building will be as cool as 65 degrees to keep the RH from dipping too low. Remember, for every 1ºF the temperature decreases, the relative humidity increases 1.4%. So a change of 9°F can change the RH by 13 percentage points without introducing mechanical humidification or dehumidification. This is usually enough to keep the gallery RH within safe levels during the spring and fall. Our guides have learned to wear an extra sweater if it is cool and dry outside, because that means it will be 65 degrees inside.

λ **Mike JC Truck**

Many companies manufacture reliable digital controls, Honeywell, Andover, Control Pak, Johnson Controls, and ASI, are the larger companies. Once properly programmed, any of these digital systems can work very well. The challenge is in designing simple control sequences and developing a good relationship with a control technician who understands these somewhat unconventional control strategies. Select the control company with the best reputation for customer service in your area and install the control brand that they sell and service.

λ **Vaisala RH Sensor** **PEM** **Hygrothermograph**

A crucial aspect of a successful environmental control system is a good monitoring program and reliable, consistent humidity sensors. We have over 100 temperature and relative humidity sensors hard-wired to our climate control computer, λ 27 Preservation Environmental Monitors with access to online climate analysis and Climate Notebook Software, λ and 7 hygrothermographs to continually monitor conditions in our buildings. λ To control HVAC equipment, I have found that sensors from the Finnish company Vaisala are best for accurately sensing relative humidity at the low and high temperatures sometimes experienced in our less than ideal environments. Relative humidity sensors that control equipment should be calibrated at least yearly, every 6 months in critical buildings. I spend about 20% of my time monitoring, adjusting, and troubleshooting environmental control systems in 22 buildings. Without the computerized building control system and reliable sensors, it could be a full-time job.

λ **Collections Preservation Building Photos**

Practical Environmental Control for New Buildings

So far, I have been addressing improving environments in historic buildings. For those of you who store and exhibit your collections in newer buildings, it's time to wake up.

In 2000, planning began for construction of a new 10,000 sq ft, two story storage building. A simple well-insulated modern barn-like building was proposed for construction on a well-drained site. The building was originally designed to utilize the practical environmental control principals and systems successfully employed in our historic collection buildings, i.e. conservation heating and ventilation.

λ **People Spaces** **Vapor Barriers**

During the planning process, our new director decided to include a library and collections management space on the second floor, introducing people into the structure. Since complete climate control including winter humidification and summer cooling and dehumidification was now required, an aluminized polyester film vapor barrier was carefully installed and taped throughout the entire building during construction. Conservation heating and ventilation were still deemed sufficient to maintain a safe environment for the carriages, furniture, wood sculpture, metals, glass and ceramics to be stored in the 5000 sq ft first floor. The cost of the building doubled from $600,000 to $1.2 million because of the requirement to keep human occupants comfortable year-round.

λ Empty Storage Area **Historic Barn**

There were a few surprises when the new building came online in 2002. Fortunately, we had planned to keep the storage area empty during the first winter to evaluate the building systems before loading in artifacts. We planned to withhold heat and allow the first floor storage area to go cold during the winter to maintain a reasonable relative humidity level of at least 35% without adding moisture, a successful practice in our historic barns. We soon discovered that this new construction was nothing like our cold, damp, wooden historic barns where high relative humidity was the major problem, even during cold winters. This new concrete and steel building was so well insulated that we could not sustain the temperature below 50ºF, even by blowing cold outside air into the first floor storage area for a few hours. The heat from the ground and the fully conditioned floor above, combined with heat generated by the two ventilation fan motors brought the temperature back up to 50° within 12 hours after closing the outside air dampers. When the outside temperature fell below 0ºF, the interior humidity dropped below 20% in the 50° space.

λ Exterior Photo **Full Storage**

However, as the year progressed, we found that when the conservation heating and ventilation system serving this storage area was completely shut down, the temperature and relative humidity levels were very steady and safe, changing only gradually with outside conditions. By installing only a steam humidifier to introduce some moisture into the space during the coldest winter months, we are able to maintain a safe environment that generally ranges from 45% humidity in the winter to 60% in the summer, at temperatures that range from 50ºF in the winter to 75ºF in the summer. We can maintain these favorable conditions in such an efficient manner because this well-sealed and insulated first floor storage space is sandwiched between the ground (with a year-round temperature of about 50ºF) and a fully conditioned space above and is filled with large wooden artifacts that act as a significant humidity buffer, slowly gaining and storing moisture during the damp summer and releasing it during the dry winter.

λ Equipment Room

In essence, we are providing environmental control for a 10,000 square foot partially occupied building at the cost normally associated with a 6000 square foot building, effectively gaining 4000 square feet of environmentally controlled storage at no initial cost for HVAC equipment. Energy costs for this 5000 square foot storage area are very low. The only mechanical equipment required for the storage area are a duct mounted ventilation fan and a humidifier, and they only need to operate for about 10 weeks of the year. The building is so well insulated and sealed that the steam humidifier provides most of the heat for the occupied portion of the building during the cold winter months. Energy usage is actually highest during the spring and summer when both cooling and heating are required to super-cool and reheat the air to dehumidify the occupied portion of the building.

λ Dec Arts Storage **Cooling Coils**

Decorative Arts Storage

Another recent innovation is controlling humidity in a 3200 square foot storage building using only Conservation heating and direct refrigerant expansion (DX) cooling, as opposed to expensive super-cooling and reheating. As long as a DX unit, such as a window air conditioner, is running, it dehumidifies quite effectively. However, once it turns off, the humidity can increase rapidly. The key to effectively dehumidifying a space is to keep the air conditioner running. If the unit is undersized for the space it will run for long periods of time without cooling the space below the set point, dehumidifying quite effectively. Keeping the room warmer will also lower the relative humidity. Our goal was to keep the summer temperature below 76°F and the humidity below 60%.

λ Insulating

We began by super-insulating a 30 year-old one-and-a-half story frame structure using blown-in densely packed cellulose insulation. As mentioned previously, this hygroscopic material has a better insulating value than fiberglass and stops all air movement, and hence moisture movement, within the wall and roof cavities. The cellulose is pre-treated with a fireproofing agent, so enveloping the structure with densely-packed cellulose effectively fire-proofs the building. The cellulose is also pre-treated with borates to prevent mold growth and insect infestation in the insulation. The building was insulated during the winter and on completion the interior temperature increased from 10ºF to 34ºF simply by retaining heat from the ground.

λ Furnace

An American Standard Freedom 90 home heating furnace with Allegiance central air conditioner were installed. This state-of-the-art air conditioner and air handler is designed to increase dehumidification by varying the speed of the fan that moves the air over the cooling coils. When the cooling unit is just starting up and the cooling coils inside the air handler are not yet cold, the fan slows to decrease the airflow and keep the air in contact with the cooling coils for a longer period of time, thereby condensing more moisture out of the air.

λ PEM Graphs 2003

These charts from Climate Notebook Engineers Report show the temperature and relative humidity in Decorative Arts storage for 2003, the year before environmental improvements were made. The histograms below the graphs show the temperature and relative humidity measurements that fall within the established "safe" zones. Note the high humidity in blue on the right graph, especially during the summer.

λ PEM Graphs 2005

With the new system in place, conservation heating controls humidity whenever the outside temperature is below 72ºF, which in Vermont is most of the spring and fall and all of the winter. The heat is seldom activated in the winter because the relative humidity seldom goes above 50% when outdoor temperatures are below freezing. When the temperature is above 72ºF, DX cooling dehumidifies the space. With the exception of one brief equipment failure, temperature and relative humidity levels remained very steady during 2005, topping out at 78ºF and 60% in the summer and decreasing to 32ºF and 42% in the winter.

Any equipment failure is a potentially dangerous event. In this case, a control point contact failed in the on position locking the heat on. Fortunately, it was caught quickly. Note that the RH did not drop as much as would have been anticipated by such a large increase in temperature because of the moisture buffering capacity of the cellulose insulation in the walls and the wooden furniture stored in this building.

It cost $8,000 to insulate the building, and the entire climate control system cost only $16,000 and uses very little energy. This work was funded by a grant from the Institute for Museum and Library Services.

λ **Circus Building** **Carousel Horse**

In 2006, Shelburne Museum received funding from the National Endowment for the Humanities to improve the environment in the 525 foot long Circus Building. Because of the size, configuration, and construction of this building, it would have been very expensive to insulate the building and purchase, install, and operate conventional climate control equipment. λ In addition, the carved and painting wooden artifacts exhibited in this building remain in relatively good condition even after 50 years of exposure to far from ideal ambient conditions. Nonetheless, environmental monitoring and close inspection of the artifacts indicated that it was important to reduce high humidity levels in the spring, fall, and especially the summer to prevent mold growth on the wood and leather components of the Dentzel carousel figures and condensation on the concrete floor. Keeping sustainability in mind, we designed a minimal environmental improvement plan that required sealing the building very well instead of insulating it so that we could effectively dehumidify the space.

Mini-Split Ductless Air Conditioner and Heat Pump

To reduce high humidity, we used an environmental control technology that is relatively new to the US, a highly efficient “mini-split” ductless air conditioner and heat pump. The mini-split’s modulating heating, cooling, and dehumidification system automatically adjusts heating and cooling capacity based on load. Therefore, the cooling coils run nearly continuously at a very low level to reduce the humidity to below 65% in the summer. In the spring and fall, we can use the mini-splits for conservation heating. By setting the mini-split control to ”heat” and using our Johnson Control Metasys building management software to turn the unit on and off, we can humidistatically control the heat to dry the building on cool damp days. Although the heat pump cannot heat the space to comfort levels during the coldest winter days, significant heating is not required in the unoccupied Circus Building because relative humidity levels fall well below 50% in the winter, even in an unheated building. The three mini-split systems required to cover the entrance, exit, and center of the building cost about one-third the cost of a conventional museum climate control system and are much less expensive to operate and maintain.

λThis graph of relative humidity produced from data logged on three PEM2 dataloggers and uploaded to the PEMdata website shows that the humidity remained mostly below 70% from February to September of 2009. λThe metric for predicting mold risk indicates that even with these relatively high humidity levels, mold will not germinate in this space, and by reducing the humidity in the Circus Building below 70%, we were able to prevent condensation on the floor λ This graph displays both temperature and relative humidity. Such easy analysis of temperature and humidity data is very important to fine-tune the operation of climate control equipment. The mini-splits have four different operational modes: “heat”, “cool”, “dry” for reducing humidity, and an “automatic” setting that changes from heating to cooling at a set temperature. By selecting different modes of operation for the Mini-split for different seasons, I anticipate that I will be able to fine-tune the operation of the mini-split to keep the RH below 65%.

λ Arnemagnaean Institute of Copenhagen University

There are quite a few conservation scientists and engineers focusing on sustainable museum and archives, especially if we look toward Europe where archives without expensive air conditioning have been built and are operating successfully. In addition to James and Michael, two other conservation scientists I look to for inspiration are Tim Padfield from Denmark, and Stefan Michalski from Canada. Tim has recently published an article citing four museum buildings that show adequate climate stability without air conditioning. Because of the massive amounts of paper-based materials in library and archive collections, they are essentially self-buffering, meaning that all that paper has the capability of absorbing and releases moisture to keep a tight space at a steady relative humidity. That makes them very good candidates for minimal environmental control. This archive in Copenhagen maintains a relatively constant temperature and relative humidity year-round using only natural cooling and conservation heating. It is very well sealed with an air exchange rate of less than once in 10 hours. Note how it is well insulated against warming from the rest of the building, but lightly insulated to the outside allowing the archives to cool with the seasons to prevent low relative humidity during cold weather without adding moisture to the space. λ Note that the relative humidity varies from 50% to about 57% gradually with the seasonal changes over the year while the temperature varies from 60° to 72°F. If you find these building environments interesting, go to Tim Padfield’s web site at Conservationphysics.org to read the article and for many understandable and entertaining articles on practical environmental control.

λ Incorrect Relative Humidity Drawing

Another simple drawing from Stefan Michalski’s chapter on “Incorrect Relative Humidity” emphasizes some very simple actions that can greatly improve the environment for artifacts in any storage space large or small, with some or no climate control. The unimproved storage space is on the left and the improved storage is on the right. (explain) Such simple fittings and packaging can extend the life of these artifacts for hundreds of years, with the use of very little energy.

λ IMLS

In closing, I have presented many ways to create sustainable environments for heritage collections. My favorite are those that are cheap, but eventually, one runs out of cheap improvements and must search for funding for more substantial environmental improvements. Fortunately, funds are available from two Federal agencies. The Institute for Museum and

Library Services' Conservation Assessment Program is targeted to historic societies and smaller museums and supports a general conservation survey that includes an assessment of environmental conditions.
The Conservation Project Support Grant is up to $150,000 and must be matched 1:1. It supports all conservation activities including full-scale environmental surveys and improvements and storage improvements.

λ NEH

The National Endowment for the Humanities has two grants designed to support environmental improvement projects of all sizes, from the smallest to the largest. Their Preservation Assistance Grants for small institutions are up to $6000 and do not require a match. They can even go to all-volunteer non-profit organizations, as long as they have the equivalent of one full-time staff member and are open 120 days a year.
A new grant, Sustaining Cultural Heritage Collections, is designed to address just they types of practical climate control systems I have discussed. Planning grants of up to $40,000 can fund visits by professionals to help the institution design a sustainable environmental improvement project. They can cover up to 80% of the total project costs. Implementation grants generally cover up to 50% of total project costs and might be used to:

- manage interior relative humidity and temperature by passive methods such as creating buffered spaces and housing, controlling moisture at its sources, or improving the thermal and moisture performance of a building envelope;
- install storage systems and re-house collections;
- install or re-commission heating, ventilating, and air conditioning systems

For anyone who is still awake, these projects should sound familiar.
I believe re-commissioning to be particularly important, especially for large museums and libraries. I doubt that many HVAC systems that are more than 7 years old are operating even close to full efficiency, and the older the system, the less efficient it probably is. These grants will pay to bring in professional engineers to examine the entire system and re-commission it to operate to original or modified specifications with an emphasis on energy efficiency and savings. The results of such fine-tuning and upgrading of older systems could save the institution significant money for years into the future and cover the institutions 50% grant match within a few years.

Laura Word from the NEH is here to answer any questions you may have about this exciting new funding opportunity.

λ Reference List

Thank you for your attention.