Providing Safe and Practical Environments for Cultural Property in Historic Buildings… and Beyond

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INTRODUCTION

Although I did not know it at the time, from the day I started as a newly trained conservator at Shelburne Museum in 1982, I stepped onto the path of creating and maintaining efficient, sustainable preservations environments. I quickly discovered that if I was to have any success in preserving over 150,000 artifacts exhibited and stored in 29 buildings that included many historic structures spread over 40 acres in the harsh Vermont climate, any environmental control methods I developed would have to be affordable to purchase and install, economical to operate, and easy to maintain, in other words: sustainable.

Twenty-five years ago, 20ºC/68ºF (+ /– 2 degrees) and 50% relative humidity (+/– 3%) were generally accepted as the required temperature and humidity limits for the preservation of collections. However, as I became more familiar with Shelburne's varied collections and the buildings that housed them, and researched museum and historic building environmental standards of other countries, 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. 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 many had experienced minimal environmental control and been repeatedly exposed to seasonal temperature extremes of -18ºC/0ºF to 32ºC/90ºF and relative humidity extremes of 10% to 95%. The artifacts in poor condition had been damaged by extreme conditions in attics that were too hot, basements that were too wet, or in dry buildings that were heated in the winter but had no humidifiers.

SUSTAINABLE STRATEGY

I determined that even though Shelburne Museum may not be able to achieve "ideal" museum environments for all its artifacts, conditions could be significantly improved by reducing relative humidity extremes surrounding historic artifacts. By keeping the relative humidity below 65% in the summer, mold growth could be avoided and significant swelling of organic materials could be prevented. By keeping relative humidity above 35% in the winter, desiccation of collections could be avoided. Research indicated that our Canadian neighbors, just 100 kilometers to the north, had been following these wider relative humidity standards for several years.[1] In the early 1990s, researchers at the Smithsonian's Conservation Analytical Lab would determine that these broader standards were safe for the large majority of historic artifacts.[2] In addition, Shelburne's artifacts had been "proofed" by high and low relative humidity extremes for many years. The worst damage had already been done. By narrowing the range of relative humidity artifacts would experience in the future, we would insure that no new damage would occur even if the new environmental conditions were not ideal.

Adopting broader relative 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 relative humidity extremes that cause most artifact damage. Of course, whatever environmental improvements we devised would have to be efficient and affordable. Even if we could afford to purchase and install the equipment to create more ideal climates, the cost of operating and maintaining such equipment would be prohibitive.

BUILDING CLASSIFICATIONS

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. As of 1985, only four of Shelburne's collections buildings had been built as galleries, and even they had little insulation and no vapor barriers. We knew that moisture introduced into such structures during a cold Vermont winter could result in serious building degradation. Fortunately, Ernest Conrad had just established his firm 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. In the course of his survey of Shelburne's structures, he devised a building classification system, later included in the 2003 American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Applications Handbook – HVAC Applications, Chapter 21, Museums, Libraries, and Archives.[3]

> **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.

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[1] R.M. Eames, The historic house in climatic extremes: Problems and proposals, *Conservation Within Historic Buildings.*, Eds. N. S.Brommelle, G.Thomson, and P.Smith (London: International Institute for Conservation, 1980) 32-33; G. deW.Rogers, The ideal of the ideal environment, *Journal of the International Institute for Conservation–Canadian Group* (Ottawa, Ontario: IIC-CG, 1976)34-39; ROM, *In search of a black box.* Proceedings of a workshop on microclimates. (Toronto, Ontario: Royal Ontario Museum, 1979).

[2] D. Erhardt and M. Mecklenburg, "Relative Humidity Re Examined." *Preventive Conservation: Practice, Theory, and Research. Preprints of the Contributions to the Ottawa Congress* (London: The International Institute for Conservation of Historic and Artistic Works, IIC, 1994).32-38.

[3] E. Conrad, *A table for classification of climatic control potential in buildings* (Norwalk, CT: Landmark Facilities Group, Inc., 1995).

Figure 1. Class 1 Building, Cambridge Covered Bridge.

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.

Figure 2. Class 2 Building, Horseshoe Barn.

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

Figure 3. Class 3 Building, Prentis House.

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

Figure 4. Class 4 Building, Dorset House.

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.

Figure 5. Class 5 Building, Pleissner Gallery.

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

Figure 6. Class 6 Building, Shelburne Museum Library.

ENVIRONMENTAL IMPROVEMENT ACTIONS

Armed with the knowledge of what our collections could withstand and what our buildings could safely support, we were ready to design and install 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. Since it is unwise to design and install mechanical systems to reduce moisture in a building or filter out dust without first taking steps to reduce such problems at the source, our first actions included installing rain gutters on buildings and storm drain systems to move water away from buildings, applying calcium chloride to dirt roads to reduce dust, and tightening up buildings by insulating walls, weather-stripping doors, and installing interior storm windows. Tinted, UV filtering Plexiglas interior storm windows also significantly reduced harmful light entering collection areas.

Conservation Ventilation

Conservation ventilation was installed in nine of our Class 2 barn-like structures, since it was apparent that, during the summer, heat and relative humidity built up inside many of our historic structures, especially on upper levels on hot afternoons. The key to Conservation Ventilation is using a humidistat to control fans rather than a thermostat. When the inside temperature exceeds 18°C/65°F and the inside relative humidity is higher than the outside relative humidity, the fans are activated and the hot, moist, interior air is replaced by cooler, drier air from outside. A consulting engineer calculated that it would require about seven air changes an hour to effectively exhaust the building and bring in outside air. However, simply installing and operating whole-house exhaust fans would solve one problem, but create another by introducing seven times as much dust into the collections areas. This problem was solved not only by exhausting air through the attic, but also by using fans to draw air into the first floor or basement of the building through filters that trap the dust.

Figure 7. Basement intake fan assembly showing dust filter pulled out.

The fans forcing air into the building are larger than the exhaust fans so that the entire building is slightly over-pressured, thereby discouraging dust from entering through open doors when visitors enter. A study conducted by the Getty Conservation Institute concluded that, on the average, conservation ventilation lowers building relative humidity levels by about 10%.[4] In addition, moving the air prevents mold growth even when the relative humidity is above 70%.

Conservation Heating

To reduce relative 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. Conservation heating is the practice of controlling the humidity in a building by adding or withholding heat. It is possible to dry out a cool, damp building simply by increasing the heat. Conversely, withholding heat and allowing a building interior to cool during cold weather will keep the humidity high enough to be safe for the artifacts even during cold Vermont winters. As with conservation ventilation, a humidistat activates the equipment, in this case a furnace or boiler. If the space relative humidity exceeds the set point (55% RH) and the space temperature is below the maximum temperature set point (22ºC/72ºF) the heat is activated. The heat is turned off when the RH drops below the set point or the temperature exceeds the maximum temperature set point. In Vermont's temperate climate, conservation heating effectively keeps the relative humidity below 55% in collection buildings during the fall, winter, and spring. Conservation heating is very efficient, since for every 1ºF that the temperature increases, the relative humidity drops by 1.4%. Therefore, only small amounts of heat are generally required to reduce relative humidity to 55%, even during the damp, rainy seasons. During the winter, the heat is seldom called on as the relative humidity drops to a minimum of about 30% in our coldest and driest buildings. Although the buildings are uncomfortably cold, this method works very well for Shelburne Museum, since it is closed to public visitation from November through April.

Cold temperatures do not harm artifacts usually found in historic house museums, as long as items such as furniture are not moved or handled when they are very cold. In fact, the low

[4] Shin Maekawa, Report on the Efficacy of Environmental Improvements Implemented in Prentis House, Horseshoe Barn, and Stagecoach Inn at the Shelburne Museum, VT (Unpublished manuscript, 1999).

temperatures reduce the rate of deterioration caused by chemical reactions in wood, paper, textiles, photographs, and other organic materials. One exception is paintings on canvas. Since research has shown that cold temperatures can cause the paint and ground layers to crack, we remove paintings from our historic houses that use conservation heating and store them in a warmer, humidified storage facility for the cold winter months.[5]

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 quilt 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, and then reheating the air to reduce relative humidity before the conditioned air is discharged into the galleries. However, we do not introduce any moisture into this poorly insulated structure during the winter, choosing instead to allow the building to go cold to keep the relative humidity around 35%. Withholding heat saves money, and allowing temperatures to drop as low as -18ºC/0ºF also slows chemical degradation and discourages insect activity in the textiles housed in this gallery.

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 vermiculite insulation and tight interior storm windows. Care must be taken to minimize the amount of moisture introduced into a structure with limited vapor retarding ability, since water vapor can penetrate the walls and condense inside, damaging the wood structure. During the winter, the building temperature is reduced to 13ºC/55ºF and a steam humidifier is used to introduce a minimum amount of moisture to maintain relative humidity levels between 35% and 40%. At such a low interior temperature, it is very 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 engineer advised that moisture should not be introduced into buildings at temperatures below 13ºC/55ºF, because at lower temperatures even small increases in air moisture content can significantly increase the relative humidity and the risk of condensation on cold interior surfaces.

Humidified Class 4 structures must be carefully monitored during cold weather. By observing condensation on the inside of double-glazed windows, the coldest surfaces in the building, while monitoring RH 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 out on the coldest surfaces in the building. If droplets of water begin to run down the windowpane, the relative humidity is too high and must be reduced. From experience, we have found that if the outside temperature is above 0ºC/32ºF, we can safely humidify the building to 45% RH. As the exterior temperature drops from 0ºC/32ºF to -7ºC/20ºF), we allow the relative humidity inside the structure to fall to 40%. As the outside

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[5] M. Mecklenburg and M. McCormick-Goodhart, and C. Tumosa, "Investigation into the Deterioration of Paintings and Photographs using Computerized Modeling of Stress Development," *Journal of the American Institute of Conservation* (Washington, D.C.: The American Institute for the Conservation of Historic and Artistic Works, 1994) 153-170.

temperature drops from -7ºC/20ºF to -12ºC/10ºF, the relative humidity set point is automatically and gradually reduced to a minimum of 35%.

DIGITAL CONTROLS AND MONITORING

None of the environmental control methods described could be practically employed without the use of digital controls. The 1991 NEH grant provided funds to connect all 27 collections buildings through underground wiring and to purchase and install digital controls, and in our case, the Johnson Control Metasys building management system. Although actual control of the various building systems is decentralized to 12 control panels that operate independently if communications are disrupted, all the systems can be monitored and adjusted from a central computer.

Many companies manufacture reliable digital controls: Honeywell, Andover, Control Pak, Johnson Controls, and ASI are a few in the United States. 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. Check references carefully.

The second crucial aspect of a successful environmental control system is a good monitoring program and reliable relative humidity sensors. We have over one hundred temperature and relative humidity sensors hard-wired to our climate control computer, and use 5 Preservation Environmental Monitors (with Climate Notebook analysis software) and 8 hygrothermographs to continuously monitor conditions in our buildings. In our experience, sensors manufactured by the Finnish company Vaisala are best for accurately sensing relative humidity at the temperature extremes sometimes experienced in our less than ideal environments. Relative humidity sensors should be calibrated at least yearly, or every six 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.

AND BEYOND… PRACTICAL ENVIRONMENTAL CONTROL FOR NEW BUILDINGS

Since conservation heating and ventilation and the use of modified, conventional HVAC systems were working well in our historic buildings, it was decided to extend these practical environmental control ideas to new buildings. The opportunity arose when we lost the use of a significant off-site storage building and it became apparent that it would cost less to build a new structure on-site than to lease existing off-site storage with even minimal environmental control.

Collections Management Building

In 2000, planning began for construction of a new, 930 square meter/10,000 square foot, two-story storage building.

Figure 8. Collections Management Building.

A 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, such as conservation heating and ventilation. During the planning process, our director decided to include a library and collections management space on the second floor, introducing people into the structure and reducing storage space by 40%. Since conventional winter humidification and summer air conditioning was now required for the occupied space, an aluminized polyester film vapor barrier was added to the building specifications. 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 465 square meter/5,000 square foot first floor. The cost of the building doubled from $600,000 to $1.2 million because of the requirement of an elevator and a conventional HVAC system for the occupied second floor.

There were a few surprises when the new building came on line in 2002. Fortunately, we had planned to keep the storage area empty during the first winter to evaluate the building systems before loading in collections. We had 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 humidity was the major problem, even during cold winters. The new concrete and steel building was so well insulated that we could not successfully reduce the temperature below 10ºC/50ºF, even by blowing cold 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 in the storage space, prevented the storage area from cooling below 10ºC/50ºF for any appreciable length of time, and when the outside temperature fell below -18ºC/0ºF, the interior relative humidity dropped below 20%.

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 steady and safe, changing only gradually with outside conditions. The storage area relative humidity seldom exceeded 60% during the winter, spring and fall, and summer temperatures remained below 24ºC/75ºF with summer relative humidity levels topping out at 65%. By installing 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% RH in the winter to 60% RH in the summer, at temperatures ranging from 10ºC/50ºF in the winter to 24ºC/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 10ºC/50ºF, and the fully conditioned space above, and is also filled with large, wooden artifacts that act as a significant humidity buffer. The "Engineer's Report" generated by Climate Notebook analysis software shows temperature and humidity measurements for 2006 in this storage space.

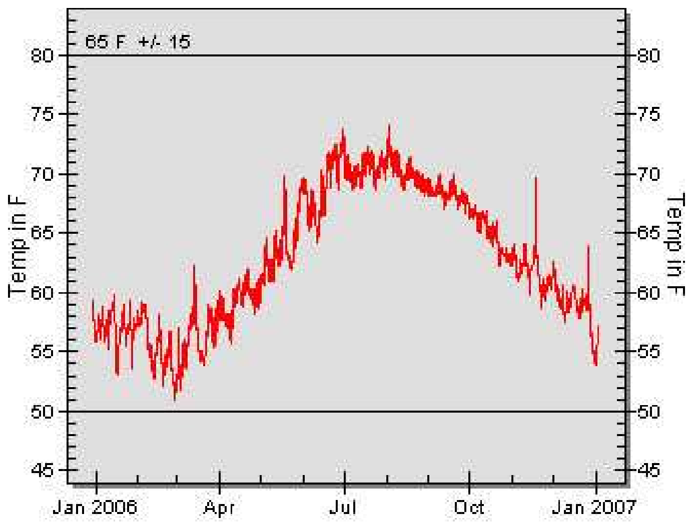

Figure 9. 2006 Climate Notebook Engineers Report for Collections Management Storage Area.

In essence, we are providing environmental control for a 930 square meter/10,000 square feet partially occupied building at the cost normally associated with a 550 square meter/6,000 square foot building, gaining 370 square meters/4,000 square feet of environmentally controlled storage at no initial cost for HVAC equipment. Energy costs for the 465 square meter/5,000 square foot storage area are also very low, since maintaining preservation conditions for the stored collections requires operation of a circulation fan and humidifier during only the two coldest months 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 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.

Decorative Arts Storage

Another recent innovation is controlling relative humidity in a 300 square meter/3,200 square foot, infrequently accessed storage building using only conservation heating and direct refrigerant expansion (DX) cooling, as opposed to expensive super-cooling and reheating that requires running air conditioning and heating at the same time for three seasons of the year.

Figure 10. Decorative Arts Storage Building.

The Climate Notebook Engineer's Report shows the temperature and relative humidity in Decorative Arts Storage for 2003, the year before environmental improvements were made. The histograms show the temperature and relative humidity measurements that fall within the established "safe" zones. Note the high relative humidity, indicated in blue on the right chart, especially during the summer.

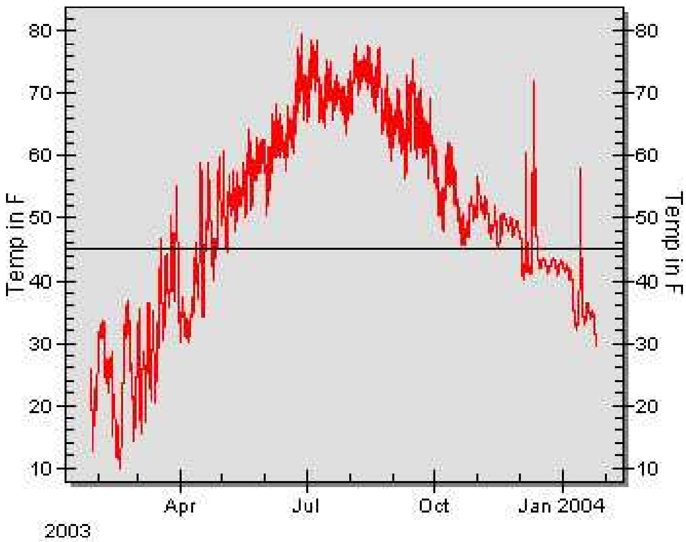

Figure 11. 2003 Climate Notebook Engineers Report for Decorative Arts Storage prior to environmental improvements.

As long as a direct refrigerant expansion cooling unit such as a window air conditioner is running, the space is dehumidified quite effectively. However, once the unit turns off, the relative humidity can increase rapidly. The key to effectively dehumidifying a space using direct refrigerant expansion cooling is to keep the air conditioner running. If the unit is undersized for the space, it will run for longer periods of time dehumidifying quite effectively without making the space too cold. Keeping the room warmer will also lower the relative humidity. The goal is to keep the summer temperature in the Decorative Arts Storage building below 25ºC/77ºF and the relative humidity below 60%.

We began by super-insulating a 30-year-old frame structure using blown-in, densely packed cellulose insulation. This hygroscopic material has a better insulating value than fiberglass battens and stops all air movement, and hence most moisture movement, within the wall and roof cavities. The cellulose is treated with a fireproofing agent, so enveloping the structure with densely-packed cellulose effectively fire-proofs the building. The cellulose is treated with borates to prevent mold growth and insect infestation in the insulation. The building was insulated during the winter, and, on completion, the building interior warmed from -12ºC/10ºF to 5ºC/40ºF simply by retaining heat from the ground.

An American Standard Freedom 90 Comfort-R home heating furnace and Allegiance air conditioner was installed. This state-of-the-art gas furnace is designed to increase dehumidification by varying the speed of the fan that moves the air over the cooling coils. When the direct refrigerant expansion cooling unit is just starting up and the cooling coils inside the air handler are not yet cold, the fans slow 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.

A difficulty in applying the “DX cooling for dehumidification” concept is that most engineers in the United States tend to over-size air conditioning units for buildings to insure that the occupants remain cool even on the hottest days of the summer. Therefore, they are not accustomed to sizing a direct refrigerant expansion cooling unit to run continuously to reduce the building temperature to only 25ºC/77ºF. Engineers calculated that a 5 kilowatt to 10 kilowatt cooling unit would be required to effectively cool and dehumidify this building. The insulating contractor estimated that a 3 kilowatt unit would be more than adequate to cool the space, especially if we wanted it to be undersized to maximize dehumidification. To ensure that we had enough cooling, a two-staged 5 and 10 kilowatt unit was installed. After two summers of operation, the second stage has never been called on and the interior temperature remains below 20ºC/68ºF even on the hottest summer days. The estimate of 3 kilowatts of cooling for an undersized unit to dehumidify this very well insulated, infrequently accessed storage space was correct.

The museum’s Johnson Controls Metasys digital building management system is used to control the American Standard heating and cooling system so that conservation heating reduces high humidity whenever interior temperatures are below 22ºC/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 interior relative humidity seldom goes above 50% when outdoor temperatures are below freezing. When the temperature is above 22ºC/72ºF, direct refrigerant expansion cooling dehumidifies the space. With the exception of one brief equipment failure, temperature and humidity levels remained very steady during 2005, topping out at 26ºC/78ºF and 60% RH in the summer and decreasing to 0ºC/32ºF and 42% RH in the winter.

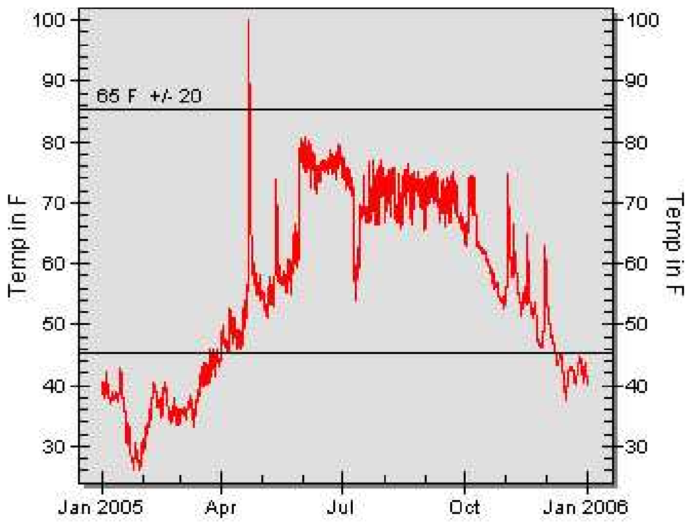

Figure 12. 2005 Climate Notebook Engineers Report for Decorative Arts Storage after environmental improvements.

The equipment failure during April of 2005 is a good reminder that even practical climate control systems require constant and careful monitoring to insure that safe conditions are maintained. Outside temperature and humidity conditions for 2004 are included for comparison.

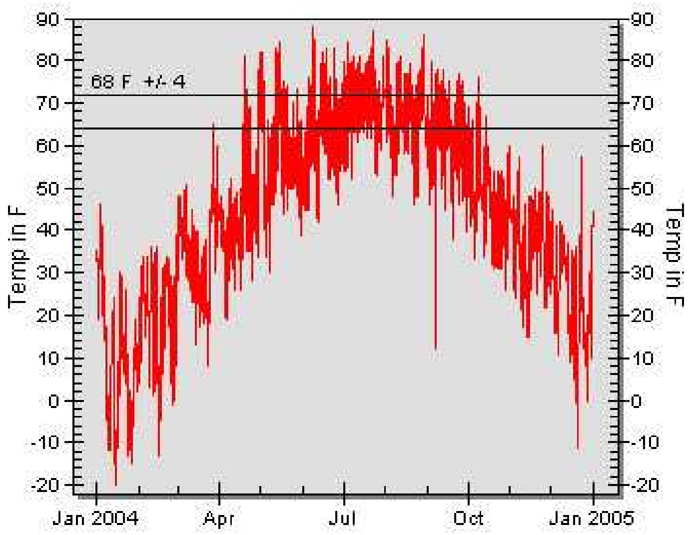

Figure 13. 2004 Climate Notebook Engineers Report for Outside Environment, Burlington, Vermont.

It cost $8,000 to insulate Decorative Arts Storage. 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, a US government agency that funds conservation and collections care projects.

The Circus Building and Split Ductless Air Conditioners and Heat Pumps
Shelburne Museum has recently received funding from another US government agency, the National Endowment for the Humanities, to insulate its 152 meter/500 foot long Circus Building and install conservation heating and cooling. Because of the size, configuration, and construction of this building, it would be very expensive to insulate the building and purchase, install, and operate conventional climate control equipment. 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 indicate that it is important to reduce very 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 have designed a minimal environmental improvement plan that requires sealing the building very well instead of insulating it so that we will be able to effectively dehumidify the space.

To mitigate the high humidity conditions, we plan to use an environmental control technology that is relatively new to the US, a highly efficient "mini-split" ductless air conditioner and heat pump. Since the mini-split's modulating heating, cooling, and dehumidification system automatically adjusts heating and cooling capacity based on load, it can cool and dehumidify to reduce the humidity to below 60% in the summer. In the spring and fall, the heat pump will be humidistatically controlled by the Johnson Control Metasys system to reduce relative humidity using conservation heating. Although the heat pump cannot heat the space to comfort levels during the coldest winter days, significant heating will not be required in this unoccupied building because relative humidity levels fall well below 50% in the winter, even in an unheated building. The proposed system is about one-third the cost of a conventional museum climate control system and much less expensive to maintain and operate.

CONCLUSION
It is important to emphasize that all of these practical environmental improvement methods have disadvantages as well as advantages, and the decision to use them involves careful compromise. Conservators must know their collections intimately to insure that artifacts requiring more stringent temperature or relative humidity conditions than practical environmental improvements provide are stored or exhibited in more tightly controlled area. Fans used for conservation ventilation can be quite noisy, and fan filter boxes need to be added to historic structures. Conservation heating results in cold buildings that are inhospitable to off-season tour groups or education classes. Comfortable access to collections is definitely limited during cold weather. Hot air furnaces are a risk in collection areas. If not properly maintained, furnace fireboxes can rust and crack resulting in puff-backs of soot that could contaminate collections. Unconventional systems are not well understood by some HVAC contractors and engineers. Therefore, careful selection, training, and close supervision is necessary to ensure the systems are properly designed, installed, and maintained. As with traditional HVAC systems, a conservator or well trained collection care specialist who thoroughly understands the systems needs to regularly monitor building environmental conditions and trouble-shoot equipment problems.

However, such compromises can definitely pay off in lower equipment and installation costs, lower fuel costs, and lower maintenance costs for less and simpler equipment. By knowing the environmental conditions that will and will not harm our collections, by embracing broader safe temperature and relative humidity standards, by using new energy efficient technology, and by working with nature instead of against it to eliminate temperature and relative humidity extremes, we can preserve our collections and historic buildings for future generations and afford to keep our museum doors open for future generations to visit.

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ROM. 1979. *In search of a black box.* Proceedings of a workshop on microclimates. Toronto, Ontario: Royal Ontario Museum.

SUPPLIERS
Preservation Environmental Monitor and Climate Notebook Software
Image Permanence Institute
Rochester Institute of Technology
70 Lomb Memorial Drive
Rochester, NY 14623-5604
www.imagepermanenecinstitute.org

Metasys Building Management Software
Johnson Controls Incorporated
5757 N. Green Bay Avenue
P.O. Box 591
Milwaukee, WI 53201
www.johnsoncontrols.com

Temperature and Humidity Sensors
Vaisala, Inc., Boston Office
10-D Gill Street, Woburn, MA 01801, USA
www.vaisala.com

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