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MUSEUM MICROCLIMATES

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Trends in microclimate control of museum display cases

Jerry Shiner

This historical review of microclimate control in museum display cases reflects the changes in approach to museum microenvironmental control that have arisen with new technologies over the past hundred years. A variety of approaches to controlling the environment within display and storage cases has been developed. An explanation of these various microclimate control techniques is provided, with an emphasis on recent developments in active microclimate control systems.

Introduction

When a society elevates an object to a symbol, demands arise for its safe handling and preservation. Whether simply stored or fancifully displayed, we design and create environments to protect these objects from known threats. Our ability to protect artefacts from harm is always trailing just a little behind the ever accelerating developments in the analysis of the world around us. The microenvironmental control methods we use constantly change as our technologies and analytical techniques expand.

Ancient history

Museum display case microclimates involve enclosures, and this survey must start with the development of the museum enclosure itself. Some cite the Ancient Greeks as the first to record ideas on the design of storage facilities, where practical consequences of orientation and construction on the environment are discussed. However, the most obvious examples of purpose-built storage structures are in Egypt. Primarily seen as impressive symbols of power, the architects of the pyramids also attempted to protect the materials they enclosed by incorporating environmental control. Whether by chance or good design, these massive tombs have maintained fairly constant environmental conditions within them over millennia.

Museum microclimates

A microclimate is an environment that can be clearly defined (both by measurements of the environment, and by location). For our purposes a microclimate is usually a contained space, such as the burial chamber of a pyramid, a museum gallery, or a storage or display cabinet. Enclosure isolates the inner (microclimate) environment from the outer (ambient) environment.

While a museum gallery's roofs and windows may reduce levels of pollutants, inclement weather, and daylight, they may also create pockets of dangerously high or low humidities, off-gassed pollutants, and over-illumination. Similar situations can be produced by any successive barrier system incorporated into the larger ambient environment. The establishment of any microclimate becomes a two-edged sword, its benefits usually obvious, and its dangers often less apparent. The history of display case microclimates is rooted in the mechanics of creating display cases, the development of appropriate methods of controlling the case environment, and the technical innovations applied to microclimate control.

Creating the modern display case

By the middle of the nineteenth century, modern industry was providing relatively inexpensive and easy to assemble materials. The Crystal Palace, built in 1851 in London, exemplified the new Age of Industry. Created almost entirely of iron and glass, the structure used glass sheets 49 inches square fitted with tolerances close enough to create an essentially leak-proof roof. Architecture had provided the model for the modern display case.

Nineteenth century microclimate control - threats and responses

By the middle of the nineteenth century, it was recognized that pollution from burning coal gas was harming the leather bindings in London's libraries, as well as the paintings in the National Gallery. An architectural response to the problems of indoor pollution from burning gas for illumination was to increase ventilation to exhaust the soot and toxic gases. While air borne pollution was a relatively new problem, dampness (a factor in metal corrosion and the growth of moulds) had long proved more of a challenge for microclimate control. Beyond the use of building heat to reduce humidity on cold and damp days, true control of a building's humidity levels would need to wait until the early twentieth

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century for large scale mechanical solutions. Smaller scale microclimate solutions would have to wait even longer.

By 1850 the National Gallery in London was glazing paintings to protect them from airborne pollutants. One of the earliest references to a sealed enclosure especially designed to create a microclimate environment is an 1892 patent [1] for a sealed case used to protect a painting by JMW Turner in 1893. When originally sealed into the patented enclosure, the Turner painting was perceived as the most deteriorated of a group. The painting has remained undisturbed in the case since then, and when compared to its companion paintings, all of which have been conserved during the last hundred years, it now looks to be in far better condition! [2]

Early twentieth century developments

In 1932, another patent was awarded [3] for a museum case providing passively controlled humidity levels. As in the earlier example, this patent again specified the use of a very well-sealed case but also incorporated a tray of saturated salts. As long as the case remained sealed, and the temperature remained stable, the mixture of salts would maintain a constant relative humidity by passively buffering the moisture content of the air. A case using this system was used in the National Galleries of Scotland for the containment of a sensitive altar piece, and provided control to within 1% of the relative humidity target. [4] Saturated salt solutions were occasionally used for microclimate control in larger applications, and were still being considered in the early 1990's as an effective means of maintaining enclosed microclimates. [5]

Heating, ventilating, and air conditioning (HVAC) systems

With the turn of the twentieth century had come developments in air conditioning and building design, as well as the general replacement of gas flame lighting with cleaner electric lights. Filtering and humidifying of air in the whole gallery became possible in newer buildings (where the will to invest in, and maintain this expensive option existed). Humidity and temperature control were still quite limited, and older buildings would have to cope with existing methods of climate control.[6]

By the mid-thirties, new developments in motor and fan design, ductwork, air cooling and architecture were taking hold. New technologies became available

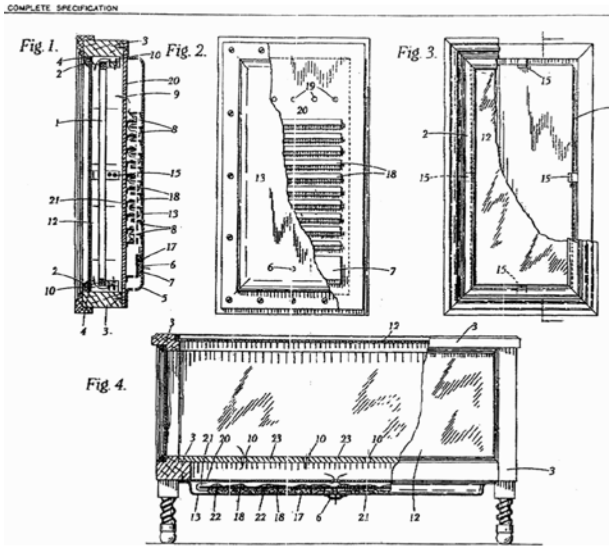

Figure 1. British Patent 396439, 1932 for a passive humidity controlled display case

for air conditioning galleries. Unfortunately, capital and operating costs for this kind of control were (and remain) very expensive. In addition, buildings must be especially designed to take advantage of these technologies, and very unpleasant conditions still may result when an older structure is retrofitted with newer building climate control technologies.

Ventilated cases

In a building using HVAC control, an artefact may need little more than protection from dust and curious or larcenous fingers. Indeed many display cases in the last century were designed to encourage the inflow of conditioned room air. However, air conditioned museums were in the minority, and in these museums a very limited range of environmental conditions could be maintained in each gallery. As some artefacts needed very particular, and different conditions for safe display, a leaky or ventilated case might not be suitable. Specialized microclimate enclosures would still be needed.

An early active microclimate enclosure

In 1938, a well-sealed display case with mechanical humidity control was built by Bill Young to create dryer than ambient conditions for an Egyptian bust in the Boston Museum of Fine Arts [7]. The gallery could not be controlled to the low humidities necessary to protect the object. Young's showcase used an electric pump (an advance then possible due to the nearly ubiquitous availability of electric power) to move air from the display case past an absorbent compound. With the simple addition of a motorized mechanism to control air flow to a substance that was usually

Figure 2. Electrically assisted passive humidity controlled display case, 1938

used as a passive buffer, humidity control could now be effectively provided in a sealed display case with a much larger volume than a picture frame.

The system was elegantly simple: The entire dehumidifying device was hidden in the plinth below the transparent glass case. Air was drawn from the case by a manually controlled electric pump and then forced through a bed of calcium chloride, removing much of the air's moisture before the air was re-injected into the upper display case. An interesting feature of the system was a gasometer, which moderated changes in barometric pressure. A similar method (diaphragm bags) is still used on some very tightly sealed cases.

Self buffering cases and materials

In some circumstances the materials and design of an enclosure create a self-buffering microclimate - the moisture exchange between air trapped in the enclosure and hygroscopic materials remains balanced. This is more common where the ratio of the volume of air to the buffering objects is relatively small and is often apparent in very small enclosures (e.g. a well-sealed picture frames) [8], in smaller display cases with generous amounts of cloth and wood surfaces, and occasionally in larger enclosures too (e.g. plaster walled dioramas filled with stuffed animals and other moisture-holding materials).

Silica gel passive buffers

An extension of the self-buffering concept is to provide a purpose-made buffering material that can be added to the showcase. A large number of organic materials could be used; over 1700 pounds of canvas hose was proposed for The Orangery of Hampton Court Palace in 1934 [6]. Inorganic silica gel offered many benefits, including seemingly infinite capacity for reuse. It was originally developed at the end of the First World War as a desiccant. In general use outside museums silica gel is usually first heated to remove moisture and is then used to capture and sequester humidity.

However, museum microclimate buffering uses silica gel's capacity to both retain and easily release moisture. This application uses a very small range of its moisture holding capacity, and regular silica gel is not very efficient as a buffering material. By varying the microscopic attributes of this material, silica gel can be tuned to form different grades, which provides more effective buffering in the range of normal museum storage humidities.

In display cases where leakage is well controlled and in an ambient environment where the average of year round humidities is close to the desired relative humidity, passive buffering can be very effective. A buffer in a case can absorb excess moisture as humid air leaks into the case and release it later when dry air leaks in. In theory, some buffers may never have to be changed. In environments where humidity conditions are consistently outside the desired target, larger quantities of buffering materials, frequent replacement, or tighter cases are needed.

By the nineteen seventies, silica gel had become a standard solution for case buffering and display cases could be ordered complete with drawers to hold a supply of silica gel for buffering [9].

While passive buffering using silica gel can be a vast improvement over cases with essentially no microclimate control, there are still significant areas where silica gel buffering proves ineffective. In some installations an inadequate transfer of moisture to and from the buffering compound into the case air results in stratification [10]. Air leakage through the case, and inadequate quantities of buffering materials can overwhelm the buffering capacity. Large cases can be especially vulnerable to these effects. Monitoring and maintaining buffers can easily be overlooked, and is often neglected.

The argument for the tightly sealed case

A well-sealed case will substantially prolong the usefulness of a passive buffer, and more effectively block external airborne pollutants from entering the case. Museums began to look at sealed cases, air leakage testing, and other aspects of microclimate case control. In the final years of the last century, showcase manufacturers were encouraged by their clients to provide ever more tightly sealed showcases [11]. Metal and glass cases were now glued with silicone to prevent leaks, new case hardware was developed, and effective gaskets replaced brushes on doors. Display cases with leakage rates of one air change every ten days - an extraordinary achievement in sealing and design - quickly became commonplace.

The argument against the tightly sealed case

While providing new levels of protection for museum objects, tightly-sealed cases also pose new threats. Complex hinging mechanisms and very effective gasketing provide extraordinary seals, but the slightest misalignment of a door or the smallest damage to a gasket can substantially change a case's leakage characteristics, especially when the original leakage rate is so low. Leaks make the enclosed microclimate far more difficult to control. If a display case is designed with provision for microclimate control based solely on the maintenance of excellent seals and minimal air exchange with the gallery, increased leakage can be a climate control challenge. Leakage testing is difficult when cases are occupied, and galleries are populated, and conservators have little time to wander the galleries.

Pollution revisited

Early on, conservators sometimes noted unusual odours in their cases, especially as the cases became more effectively sealed. Tests revealed that pollutants generated within the enclosure could sometimes be at least as dangerous as those coming in from the outside. The expansion of analytical techniques in the late twentieth century revealed even more families of deleterious chemicals and measured these chemicals in smaller concentrations. A well-sealed case will not only maintain relative humidity levels, it may also retain high levels of dangerous pollutants.

Figure 3. Trapped pollutants create pattern on glass

By the mid nineteen seventies, a number of conservators were investigating the effects of pollution in display and storage cases and were demonstrating the importance of maintaining a microclimate with very low levels of pollutants. Passive sinks for these pollutants had been suggested in the late sixties. By the mid-eighties The Metropolitan Museum in New York had created simple active microclimate pollution control units consisting of air pumps to force air through a pollution filtering canister before introducing the filtered air into display cases [9], displacing any pollution-laden air. Variations of this system were subsequently used again at the Met, as well as at the British Museum.

The evolution of active microclimate control machines

As demonstrated by the use of various pump-assisted units, the concept of supplying conditioned air to cases was a viable solution for microclimate control, given appropriate technology. A number of attempts were made to adapt or apply building HVAC systems to supply conditioned air to display cases. In most applications it did not prove to be an appropriate solution. Eventually engineers realized that using whole gallery HVAC machinery for showcases was an approach akin to mounting a steam engine on a motorcycle. HVAC components were inherently too large, and fine control of their relatively massive output was fraught with problems.

An HVAC system is designed to control both temperature and humidity, but conservators realized that control of humidity levels alone would be their most useful application. Many chemical reactions can proceed only with the presence of water vapour, and while fluctuating temperatures might be directly deleterious to some materials, it was clear that the relative humidity swings occurring as a result of temperature variations created a more immediate danger, especially to composite and organic materials. Besides, building temperature control was generally a well-developed technology, and as heat travels fairly readily into and out of cases, maintaining consistent gallery temperature conditions generally proved easy and adequate.

Small commercial climate control units, especially made for room applications, did work, to varying degrees. In 1968 these small dehumidifiers were used at the British Museum to prevent bronze disease [12]. In other applications, humidifiers incorporating in-case humidistats were installed and later the British Museum would successfully use a combined humidifier and dehumidifier to treat a single case [13]. This pioneering work would eventually lead to a commitment to using active microclimate control devices throughout the museum. In the late sixties, the challenge of finding an appropriate technology remained.

The seductive call of microclimates

The results from the early attempts at mechanical microclimate humidity control were more than just promising - they were tantalizing. Mechanical control of the microenvironment would allow display and storage case environments to be maintained at optimum conditions, regardless of ambient relative humidity. A reactive system would adjust relative humidity levels regardless of temperature changes. There would be no buffering medium to monitor or recondition, and the systems would also remove pollution. Dust and airborne pollutants could be kept out of the cases using positive pressure systems. Individual showcases could be controlled to provide optimum environmental conditions for their contents. Even in times of relatively cheap energy, the potential savings in HVAC costs were obvious and attractive. [14] The greatest portion of operating cost for most HVAC systems is humidity control, and with microclimate cases, tight control on gallery spaces would not be necessary (1). By the late nineteen-seventies, interest in active microclimate control was running high.

Attempts at employing building HVAC systems

A number of attempts were made to harness the output of full size HVAC systems to display cases. Stories of showers of chipboard particles inside showcases [15], delicate pages fluttering [11], and condensation appearing on the interior of cases [16] continue to reverberate in the conservation community. An optimal solution continued to elude conservators and engineers - HVAC systems were too big to control, and more than a little dangerous to sensitive artefacts.

In search of the black box

In February of 1978, the conservation department of the Royal Ontario Museum in Toronto, Canada, organized a workshop called “In Search of the Black Box” [17]. Faced with an early twentieth-century building that could not be effectively controlled to modern museum standards, the workshop was called to discuss a variety of approaches towards protecting the museum’s collections on display. Amongst the topics discussed was the provision of independent mechanical solutions for display case microclimate control.

A local engineering firm was engaged to create a microclimate device suitable for the museum, with the promise of a purchase if their research proved successful. In 1984 the first production models of the Micro Climate Generator were delivered. Using not compressors, but Peltier cells to provide cooling for the mechanism, these units were miniscule when compared to building HVAC systems, or even residential models. They provided unusually steady relative humidity levels in the showcases by using a proprietary humidity modification system and delivered a stream of air at constant (target) relative humidity.

Humidity control by displacement versus addition

In the common HVAC approach to humidity control, an influx of moist or dry air is occasionally added to a body of air to modify its relative humidity. The moisture content of the air rises or falls until the target has been met, and usually decays again, often resulting in repeated spikes in relative humidity. This spiking effect can become especially pronounced in small, sealed enclosures. The Micro Climate Generator used a novel approach: a steady flow of air at the desired target humidity was injected into the case, continually displacing the existing microclimate. The recirculating flow of target humidity air was delivered at a rate often far greater than the case leakage rate. This rate of flow ensured that the case environment would remain at the desired humidity level, without overshooting or spikes.

As temperatures in the Royal Ontario Museum were relatively stable year round, the 1984 Microclimate Technology units were designed to provide a constant humidity level at a single target temperature. Soon, conservators at the Louvre pointed out that many museums did not have the luxury of well-controlled heating. In 1994 a new generation MicroClimate Generator, capable of responding to changes in ambient temperature, with advanced electronic controls and a DOS computer interface was introduced.

Other miniature systems

The MicroClimate Generator was not the only miniature device produced in the eighties. Others were produced in both the USA and Europe. All these small units used a constantly running fan or pump, but most modified case humidity by using the HVAC approach of intermittent humidification and dehumidification cycles. One of the simplest was the Artifact Preservation System (APS) in the early 1990's. The APS unit consisted of an oblong metal box containing both a bag of very dry desiccant and a wet pad as source of moisture. Computer fans, flap valves, and a mechanical humidistat controlled the mechanism. Air moved through 100 mm ducting, but the APS could be fit beneath many display cases. One of these units installed in 1995 in Bowdoin College, Maine, is still operating effectively [17].

In 1993 the MiniClima was introduced, using an electronic dehumidifier. Within the MiniClima was a small water tray set beneath an array of vertical aluminium fins in the air stream of a constantly running circulating fan. An electronic controller was connected to a sensor in the display case. When the case humidity exceeded pre-set upper or lower limits, the controller energized the appropriate mechanism. When the air in the case became drier than the lower limit, water from a reservoir was pumped into the tray, and evaporated directly into the air feed to the case. When the air in the case became too humid, an electronic cooling cell (Peltier cell) attached to the aluminium fins condensed water out of the same air feed, lowering its humidity. Condensation was collected in the tray and pumped into the reservoir.

Glasbau Hahn's active climate control system was generally only available with the purchase of their display cases. This humidity control device used a miniature pump, not a fan, to generate enough air pressure to move the air through the mechanism. Air was humidified in a chamber, and then passed over a Peltier cell cooled surface to reduce a moist flow of air to a suitable humidity. A constant flow of positive pressure air was fed to the cases through small tubes. Air injected into the case displaced case air, which was forced out of the case through leaks in the gaskets under very low pressure. In some applications, a single unit could be outfitted with multiple hoses, to deliver air to a number of showcases (to maintain similar humidities, all showcases had to be in the same temperature). The one way flow meant that no return hose was needed, but the amount of air that could be delivered by pump and narrow hose was relatively small. The recommended flow to control a case was less than one air change per day, necessitating the use of very well sealed cases and doing little to purge pollutants generated within the cases.

Large scale display case microclimate control

As we have seen, the application of large scale microclimate control for showcases was a temptation for generations of engineers. Mechanisms for room scale humidity control were well developed, but their application to museum cases needed some novel thinking.

Stephan Michalski of the Canadian Conservation Institute (CCI) published plans for a centrally located microclimate unit in 1982 [18]. This device provided a substantial one-way positive pressure flow of conditioned air to many cases. As in most other units, the "Ottawa Machine" used an additive system, switching between drying and humidifying modes to create appropriate humidity levels. Rather than dry the air by condensing water on a cold surface, the CCI unit used a commercial desiccant drying wheel to dry the air. To prevent transmission of the inevitable spikes from the drying and humidifying mechanisms, the Ottawa unit used a novel configuration of silica gel to buffer the output. By using this in-line moderator, the unit was able to produce a stream of air at constant relative humidity.(2)

The output from the CCI units was prodigious. Not only could many cases be controlled from one machine, the filtered air supply was ample enough

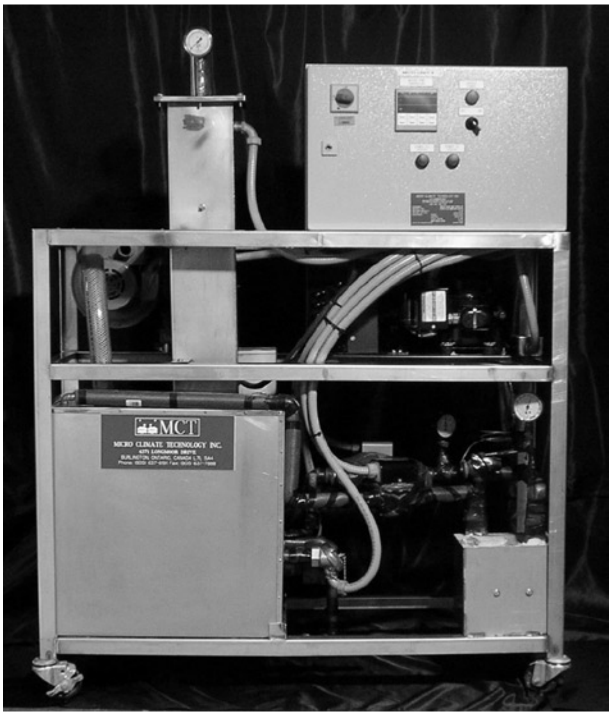

Figure 4. An early constant volume generator for positive pressure delivery, 1994

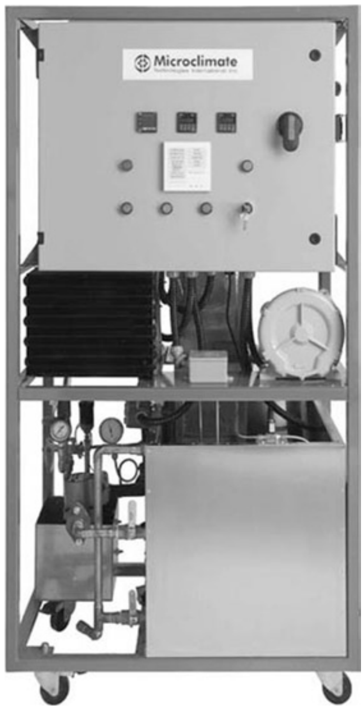

Figure 5. Recent model of a remote positive pressure unit, 2005

to effectively flush pollutants from within the cases. More than twenty units were built in the 1980's from the CCI design by Kennedy-Trimnell Inc., and used successfully in a number of North American applications [19]. The buffered moderating system was used again in an improved design published by CCI over a decade later.

In 1994 Microclimate Technologies introduced the first of a long series of large environmental control units, originally called the Constant Volume Generator (CVG). Unlike systems that combined separate humidifier and dehumidifier modules, these units utilised the same approach as their miniature units, using a single mechanism to provide a constant humidity output. As the units incorporated powerful blowers, they could be located hundreds of meters from the galleries. These positive pressure air distribution systems could feed many showcases at exchange rates of more than four air changes per day. A constant flow of clean air would also dilute and expel pollutants. No exhaust port was needed, as it was quickly discovered that no sealed museum case would contain air under pressure, and the oft predicted build up of internal case pressure did not occur.

The first installations of the CVG units at the Royal Ontario Museum, along with the success of the Ottawa Machines at the Museum of Fine Arts in Boston, the Field Museum in Chicago [20], and many other installations, proved the effectiveness of the central unit approach. In Ottawa, a second generation of CCI units installed at the Canada Science and Technology Museum included many improvements.

The Microclimate Technologies' CVG unit developed rapidly, based on continuing feedback from a large number of commercial installations. New generations of the CVG units (now known as the MCG 30) were fitted with multi-point self-diagnostic systems and isolation valves in the air distribution system to dump supply air to the gallery and seal off enclosures in the event of the humidity stream going out of range. They had better pollution filtering, improved sensor systems, and other failsafes and innovations, resulting in more effective and reliable units.

Other microclimate generators

A wide variety of units for display case environmental control have been built over the years, usually as unique systems. Many seem to have been effective, but few have been commercially viable. For example, the Royal Ontario Museum had a central unit that used alternately regenerating silica gel desiccant filters to reliably create a flow of very dry air. When it eventually wore out, it was replaced with a more conventional, commercially available microclimate system. Temperature control using electronic cooling was successfully applied in the early 1980's for very small scale applications [22], but the expense of applying cooling technology has kept cooled cases rare (3).

Low oxygen

In the early nineteen eighties, conservation scientists explored systems to remove oxygen from storage environments. Originally developed for the food industry, oxygen absorbers as well as inert gas purge systems were soon tested and applied by conservation scientists to the poison-free eradication of insects, as well as for the storage of organic and oxygen-sensitive materials. By 2000 both active and passive systems for oxygen-free display had been developed, tested, and installed, with varying success. Oxygen-free display and storage of museum objects still remains complex and rarely used. Continuing research in oxygen-free environments, as well as technical developments, cost reductions for nitrogen generators, ongoing exploration of the advantages of oxygen-free storage, and high profile projects (4) promise to change this.

State-of-the-art systems

The ultimate state-of-the-art active microclimate control system would be capable of supplying a dust, pollution, and oxygen-free, humidity and temperature controlled environment. While current technology can do it all, the cost is still substantially higher than simply controlling the humidity. However, complete environmental control is more than most applications will need - often the removal of only one factor will provide a relatively safe microclimate. In many cases, a simple (passive or active) microclimate control system providing constant humidity with some pollution control is adequate protection.

Many businesses now exist to serve the microclimate needs of preventive conservation in modern museums. Showcase makers routinely provide secure, low leakage cases. Engineers continue to improve their microclimate environmental control devices. Silica gel manufacturers have developed new and more efficient formulations. Specialized display lighting developers experiment with new light sources and technologies, and conservation scientists continue to develop new tests for known threats, find previously unknown threats, and assiduously study currently accepted methods for flaws.

All this sometimes frenetic activity is dependent on a long-standing basic human desire to define certain objects as special, and keep them for study or veneration. In this, we differ from our ancestors only in the level of science and technology now available. Our efforts may seem primitive three thousand years from now, but our responsibility remains the development and perfection of methods for ensuring the long-term stability for the objects that our society considers extraordinary.

Acknowledgements

I would like to thank the many generous people who have written articles, sent emails, or simply taken the time to share stories from their past. I would appreciate any further anecdotes or shards of memories - this history is ongoing.

Author

Jerry Shiner
Microclimate Technologies International
jshiner@keepsafe.ca

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Notes

(1) Much of the energy used to heat or cool the air in a building can be retained by heat exchangers when stale air is exhausted and fresh air brought. However, most of the very high energy cost of evaporating or condensing water to control relative humidity is lost with the exhausted stale air.

(2) The CCI unit was an interesting hybrid, using an HVAC (addition-style) microclimate control mechanism to condition a silica gel buffer and then force air through the buffer to the cases. A variation of this method was used with the environmental control mechanism for the Mona Lisa in 2005, where a small microclimate generator reconditions a box of silica gel, and a fan then circulates air through the box and into the artefact case.

(3) A temperature and humidity controlled display case was installed in 1997 in the Thomas Jefferson Building of the Library of Congress. The case is 12 feet long by 10 feet high and weighs 3 tons. It consists of a steel display chamber within an exterior of maple veneer with mahogany inlays. On either side, two large viewing windows are glazed with a specially rated ballistics polycarbonate and glass laminate. Small electronic microclimate cooling units, designed for mitigation of temperature swings, rather than complete control of temperature are now available. However, questions of expense, noise, energy consumption, and what to do with the transferred and waste heat continue to challenge both engineer and registrar.

(4) Using techniques based on the encapsulation of America's Constitution, the Library of Congress will shortly have placed their copy of the Waldseemuller map, known as "America's Birth Certificate" in a very large oxygen-free enclosure. The back and sides of the case were milled from a single large block of aluminum.