The Heritage Building Envelope as a Passive and Active Climate Moderator: Opportunities and Issues in Reducing Dependency on Air-Conditioning

By Michael C. Henry

Introduction

In the past half century, expectations of thermal comfort in North America have been shaped by the increased availability of climate control technology and equipment and by the comparatively low cost of operating these systems. As conservation professionals, we have come to expect that climate control technology can alleviate the potential damage to museum collections from extremes and fluctuations in temperature and relative humidity (RH). Both expectation levels—comfort and conservation—have resulted in sophisticated energy-intensive climate management systems for old and new buildings. This trend is now being replicated throughout the world (fig. 1).

In the latter part of this time period, the climate science community arrived at the overwhelming consensus that global consumption of fossil fuels significantly contributes to higher atmospheric temperatures, changes in climate patterns and precipitation, and rising sea levels. Against this backdrop, as stewards of cultural heritage, we should review our current approaches to environmental control and revisit traditional building design and use as part of our environmental management strategies for collections. This review may give us solutions that promote not only the conservation of our material culture but also the conservation of our global environment.

This paper considers:

- the evolving concept of thermal comfort and its definition based on available environmental control technology;
- the heritage building and its envelope as environmental management system;
- opportunities to reemploy building features in the management of the interior environment, thereby reducing the need for conventional approaches to air-conditioning;
- potential issues and risks associated with reemploying building features as an overall strategy of environmental management for heritage buildings;
- climate change and the necessity to consider alternatives to air-conditioning.

Concepts and Definitions of Thermal Comfort

Historian John E. Crowley noted that the present concept of human physical comfort emerges as a value in eighteenth-century material culture:

> Historical changes in the technology of elementary comforts depended on the existence of a fashion conscious public that was made aware of the *dis*comfort of what had been previously considered functionally adequate. The processes by which cultural imperatives shaped new patterns of consumption are particularly evident in the pre-industrial context, where changes in the design and use of domestic space and its facilities were far more dramatic than can be accounted for by technological innovations alone . . . Concern with comfort provided a rationale for moderate but innovative patterns of consumption that transcended both the aristocratic imperatives of luxury and the necessities of poverty. (Crowley 2001, 291–92)

The engineering definition of human thermal comfort is preceded by the availability of technology to address heating, cooling, and air-conditioning processes, thus reinforcing Crowley's premise that comfort is continuously redefined by technological availability and consumption, as well as by other factors. The history of the engineering definition of comfort begins in 1918 with the laboratory of the American Society of Heating and Ventilating Engineers (Cooper 1998, 101). The late-twentieth-century engineering definition of occupant thermal comfort evolved as the psychological response to physical heat and moisture balance with the thermal environment, or "that state of mind which expresses satisfaction with the thermal environment" and is expressed as specific ranges of temperature and RH conditions (ASHRAE 2005, 8.1).

However, the engineering definition must be viewed in the context of its necessity in the design process. An engineer needs a quantitative statement of desired outcomes on which to base designs for interior environmental control. The design of the system to provide these defined comfort conditions is based on identification of a control volume, usually the building envelope, and the heating/cooling, humidification/dehumidification, and ventilation loads on the control volume. Thus, a consequence of the design process is the emphasis on *resultant conditions*, *enclosure,* and *control*, since certainty in calculations is preferable to ambiguity, and since a major source of ambiguity in the actual system performance is the potential operability of the exterior envelope by building occupants (adaptive behavior). The result of the engineered approach is "the choice of design professionals, engineers and architects, who favor a controlled and rational system, a building that is so integrated with its mechanical services that it has become a machine itself and is controlled by technical authority" (Cooper 1998, 3).

Although the guidance issued to engineers acknowledges potential adaptive occupant behavior in maintaining individual comfort, the engineering concept of adaptive behavior is constrained within the presumption of a controlled interior environment: "In general, the value of using an adaptive model to specify set points or guide temperature control strategies is likely to increase with the freedom that occupants are given to adapt (e.g., by having flexible working hours, locations, or dress codes)" (ASHRAE 2005, 8.19). The engineering definition of adaptive behavior is restrictive, since others have found that if occupants are given the opportunity to exercise some control over their environment, they will tolerate a greater range of variation in environmental conditions than if they have no control, as with centralized systems (Roaf, Crichton, and Nicol 2005, 117–24).

Some argue that, in addition to a constrained definition of adaptive behavior by occupants, the engineering definition of thermal comfort does not sufficiently account for other factors, such as architectural openness: "openness, the lack of enclosure, is a perceptual condition that strongly affects expectations and thus provides a measure or prediction of thermal satisfaction that is a distinctly different set from those accepted in enclosed spaces" (Cook [2001]).

The tension between the four-season controlled artificial interior environment and an occupant-modified adaptive environment begins with the introduction of mass-market air-conditioning after World War II. It continues today as architects reexamine the energy costs of building operations and the potential benefits, economic and environmental, of building alternatives to the sealed, climate controlled building.

Expectations of Thermal Comfort, Buildings, and Air-Conditioning

Crowley's premise that eighteenth-century expectations of comfort evolved with available technology and consumption may also be applied to the redefinition of thermal comfort as a result of air-conditioning in buildings in the late twentieth century. In the case of air-conditioning, engineers, consumers, and corporations used "a variety of tactics in the seesawing power relations surrounding the development of air-conditioning, including rhetoric, models, government regulation, guarantees, industry standards, experimental science, and quantitative standards" (Cooper 1998, 5).

In 1969, when Reyner Banham published his seminal book *The Architecture of the Well-Tempered Environment*, air-conditioning was an expensive option on American cars, and central air-conditioning was available in new postwar housing. Historian Gail Cooper noted, "Largely as a consequence of modern design and construction imperatives, then, air-conditioning moved quite rapidly from a luxury to a necessity in the building industry" (Cooper 1998, 157).

When the National Building Museum presented the 1999 exhibition *Stay Cool! Air Conditioning America*, 90 percent of newly constructed U.S. homes featured central air-conditioning, and two-thirds of existing homes had central air-conditioning, while one-third had room or window air conditioners. In the same year, penetration of factory-installed air-conditioning in the U.S. automobile and light truck market approached 100 percent.

Across the United States, the availability of year-round interior climate control in buildings and vehicles profoundly changed public and personal expectations of environmental comfort and the individual's relationship with the natural environment. Systems automatically intercede in controlling the interior environment, and building design has eliminated many of the traditional features for individual control, such as operable windows and shading devices.

In the span of one generation, most people in the United States have come to expect that personal environmental comfort will be maintained continuously by heating and air-conditioning systems. As a result, we have become disconnected from the seasonal shifts of climate, its nuances, and its daily manifestation as weather. Personal observations of weather and climate are largely secondhand, reported by media meteorologists or Internet weather services, with an emphasis on the catastrophic extremes that strain our mechanical systems and energy supply infrastructure, upsetting our artificially maintained comfort.

Collections Environments and Air-Conditioning

The increased availability of environmental systems, especially air-conditioning for human comfort and industrial applications, not only influenced the definition of human thermal comfort but also provided the museum community with the technology to control the environment of collection spaces.

In the late twentieth century, with the advent of solid-state digital dataloggers for measuring and recording environmental conditions, environmental monitoring became increasingly economical. These devices were quickly embraced by museum professionals. The digital data collected could be readily analyzed and presented with personal computer software, thus alerting collections stewards to the extremes and variations in temperature and RH in their museum, library, or archives spaces.

In some instances, the data presentation and digital display could imply a level of measurement precision that exceeded the performance specifications of the logging device. One outcome was an expectation that the capability to measure interior conditions precisely implied a capability to control the machinery and systems that maintained the interior conditions with the same degree of precision. This expectation tended to be codified in environmental specifications for collections conservation.

Engineers, architects, and mechanical contractors, being problem solvers by training and inclination, were responsive to the challenge of close control for collections environments. However, the resultant systems came at a premium in installation and operating costs. Furthermore, the complexity and lack of transparency of the control systems served to distance museum personnel from the very systems intended to protect the collections.

Eventually, engineering and conservation professions jointly defined target environmental conditions for collections (ASHRAE 2003), somewhat paralleling the evolution of the engineering definition of thermal comfort conditions. For the most part, concerns with collections longevity place primacy on reducing variations and extremes in RH rather than on controlling temperature.

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) engineering guidelines (ASHRAE 2003, 21.8, table 4) address the desired psychrometric parameters as a function of (1) collections materials, and (2) class of environmental control with respect to RH and temperature set points and variability. The selection of the class of control is influenced by the building, including factors such as construction, typology, use, and systems (ASHRAE 2003, 21.9, table 5).

The ASHRAE guidance provides information on appropriate systems, notably those for the more demanding classes of control, but is silent on how to design or implement approaches that are based on operation of the building envelope.

The Heritage Building as a Passive and Active Climate Moderator

Heritage buildings that predate the development of four-season climate management systems typically had some inherent capability to moderate external influences on interior conditions. In these older structures, the building itself was the system for ventilation and human comfort. The hygrothermal performance of these buildings relied on building materials, thermal mass, moisture buffering, landscape, siting, overall form, horizontal and vertical communication among interior spaces, and exterior wall openings.

A key component of the interior conditioning of older buildings was occupant operation of building features—such as doors and windows and their associated devices such as shutters and shades—which moderated the influence of the exterior on the interior while capitalizing on favorable external aspects, such as breezes, for ventilation and comfort.

The development of the sash window in the late seventeenth century and its rapid dispersal in the Western world in the eighteenth century brought a new level of ventilation control to the exterior wall. (Louw and Crayford 1999, 185). The in-plane operation of the sash window was also highly space efficient compared to the casement window. The sash window allowed layering of other control devices such as shades, shutters, and window treatments, resulting in a multifunctional assembly that addressed natural light, views, ventilation, heat gain/loss, security, and, perhaps, openness (case study 1).

Case Study 1: Drayton Hall (1738–42)

Drayton Hall—a National Historic Landmark near Charleston, South Carolina—is interpreted in its unfurnished state as a superlative example of Georgian Palladian architecture. It is rare among heritage buildings in that it has not suffered the encroachment of modern climate management systems of any type (fig. 2).

The large window openings in the exterior walls contain multifunctional window assemblies for managing natural light, heat gain, and ventilation. Notable is the mid-nineteenth-century installation of operable louvered shutters on the interior side of the window sash, between the sash and the solid-panel interior shutters (fig. 3). The room occupant can make finite adjustments to natural light and ventilation and can secure the room by closing the shutters without leaving the privacy and comfort of the interior space.

However, architectural features for interior environmental management were not limited to operable devices in the exterior wall plane. In the eighteenth and early nineteenth centuries, external features such as verandas and piazzas that extended beyond the fixed walls of the building became especially popular in warm and hot climates of North America

(Crowley 2001, 230–59). These prominent architectural features defined a second interface between the interior and exterior at which conditions could be mediated using fabric and screens. In doing so, they created an important living space for the occupants between the exterior wall and the outer edge of the piazza or veranda.

In the nineteenth century, a variety of strategies were employed to enhance the movement of air within the building and, by virtue of density differences in air in response to temperature, augment the exchange of interior and exterior air. At the James Pitot House, subtle buoyancy-driven ventilation techniques are combined with exterior galleries to address the New Orleans climate (case study 2).

Case Study 2: The James Pitot House (early nineteenth century)

The James Pitot House in New Orleans—listed on the National Historic Register—is currently the subject of a Getty-funded Conservation Planning Grant (fig. 4). It is a traditional two-story Creole cottage interpreted as a furnished historic house museum. The house has numerous features to address the hostile New Orleans climate. Deep galleries protect the interior spaces from sun and driving rain (fig. 5).

The second-floor galleries provided protected exterior living spaces, the importance of which is evidenced by the presence of architectural trim such as baseboards and, in some instances, chair rails. Interior spaces are configured for cross-ventilation through multiple doors and windows that open onto the protected galleries.

The house incorporated seasonal operating features (no longer extant), such as curtains and shades hung above the gallery railings to provide privacy and to exclude insects when the galleries were transformed into living spaces in the hot summer months. The original loose-fit slate roof resisted wind uplift from tropical storms, and the heated mass of the roof created a nighttime thermosiphon, exhausting room air into the attic through second-floor ceilings constructed from gap-spaced painted boards, cooling the rooms below (fig. 6).

With the introduction of central air-conditioning into the Pitot House in the late twentieth century, the building underwent a variety of changes. The ventilating ceiling was closed off with attic insulation, and the roof was replaced with tight-fitting composition shingles and roofing felts. The attic is no longer a solar-powered passive ventilator, and the doors and windows to the galleries must be kept closed to stabilize the conditioned interiors. Ephemeral and fugitive methods of managing the interior climate, such as the gallery curtains shown in a delightful 1830 sketch by Charles-Alexandre Lesueur, have long disappeared.

These losses are not unique to the Pitot House. They are examples of losses of climate-specific operative features at many older buildings that have been retrofitted with centralized heating and air-conditioning systems. These changes illustrate the subtle transformation that takes place when the decision is made to control the interior climate mechanically for occupant comfort or collections conservation, or when it is necessary to secure or seal the structure against pollutants, pests, or unwanted entry.

Analysis of environmental monitoring data suggests that the thermostatically controlled air-conditioning system does not address the need to dehumidify during periods of coincident high ambient RH and moderate temperatures that frequently occur throughout the year. Furthermore, by depressing the interior ambient temperature of the building from the traditional norm, the ambient interior RH is elevated as moist exterior air enters the cooler building.

Like the Pitot House, heritage buildings that have been retrofitted with contemporary mechanical systems are likely to have had modifications to make them perform more like modern, tightly sealed buildings in an effort to achieve performance consistency and reduce air and moisture vapor exchange through the envelope. The resultant losses, which are often attritional, include:

- fugitive features, such as fabrics, shades, and screens, which are no longer used;
- operability of architectural devices, such as sashes and shutters, which may be fixed or sealed in place;
- occupant knowledge of the climate management function and operation of the building envelope, as controls supersede adaptive occupant behavior.

It is interesting to compare the losses at the Pitot House with those at the Gibson House (case study 3).

Case Study 3: The Gibson House (1859)

The Gibson House in Boston, a National Historic Landmark, is interpreted as a furnished historic house museum. It has not been fitted with central air-conditioning and retains its original three-story-high ventilation and light shaft (figs. 7–9).

These architectural features for interior climate management are typical of a multistory building in an urban context. Since the building has long windowless sidewalls, buoyancy-driven ventilation was essential to augment the limited window area provided by the narrow front and rear facades. In such cases, light and ventilation shafts, stair halls, and areaways are critical to movement of air, thermal energy, and natural light to interior spaces.

At the Gibson House, the shaft is a functionally sophisticated and architecturally refined feature. It distributed heated air to upper floors in winter and exhausted hot air from all floors in summer, while distributing much-needed natural light to windowless interior spaces and the interior stair hall. Building occupants operated the interior window sash on the ventilation shaft according to need, as indicated by the thermometer placed by one such window. The shaft now terminates in a vented skylight, which appears to be a replacement for an earlier, presumably operable version.

The impacts of centralized systems are compounded in older buildings considered historic by virtue of their architectural, historical, or cultural significance. In historic buildings, the interior environmental management must also address the preservation issues posed by the building itself. The dual mandate to preserve historic building fabric and prevent deterioration or damage to the collections sets the stage for potentially competing or conflicting objectives.

In responding to the tension between building and collections, the 1991 *New Orleans Charter for Joint Preservation of Historic Structures and Artifacts,* adopted by the American Institute for Conservation of Historic and Artistic Works and the Association for Preservation Technology International, endorses balancing the needs of both and involving both collections and building professionals in decision making. Nonetheless, the presumed necessity of a retrofit centralized heating and air-conditioning system for comfort and conservation will ultimately drive many of the decisions to alter the building envelope and eliminate the operability of original climate management features.

Opportunities to Reinstate the Heritage Building as a Passive and Active Climate Moderator

The heritage building may provide opportunities to moderate environmental conditions as an alternative to air-conditioning through a variety of environmental management strategies. The strategies will be defined by circumstances specific to the:

- comfort and/or collections objectives for the interior environment of the particular building;
- external climate;
- location, building orientation, and site, including landscape;
- form, materials, configuration, and historic significance and integrity of the building;
- the response of the interior environment to thermal and moisture loads on the building.

In the conventional mechanized approach to climate control, the engineer will design a system to offset the thermal energy and moisture loads on the building with the mechanical processes of heating, cooling, and air-conditioning. The engineer, using empirical engineering, climate, and architectural data to predict the thermal and moisture loads, will size the equipment accordingly.

The alternate strategy of using the heritage building as a passive and active climate moderator requires a more nuanced approach, in which environmental management strategies are employed to moderate or reduce the effects of the thermal and moisture loads. In this approach, actual monitoring data or computer simulations may be analyzed to determine the effect of thermal and moisture loads on the interior environment of the building, as well as to establish the potential efficacy of various passive or active environmental management strategies, such as the examples outlined below.

If interior temperatures are unacceptably high, the heat gains might be reduced by managing insolation at window openings or heat gain by the wall surfaces, rather than by introduction of mechanical cooling. Depending on the specifics of the building, this strategy might be implemented through passive and active measures such as:

- shading the building through placement of landscape plantings;
- selecting exterior wall and roof colors to reduce radiant heat gain;
- operating window shutters or shades to reduce insolation;
- increasing natural ventilation.

If interior moisture vapor loads are high, the environmental management strategy might be source reduction of moisture vapor and liquid, rather than mechanical dehumidification. Depending on the specifics of the building, this strategy might be implemented through passive and active measures such as:

- intercepting and diverting roof and surface water runoff before they are absorbed by wall surfaces and building materials;
- operating windows and doors to ventilate the building when exterior atmospheric moisture vapor is lower than interior atmospheric moisture vapor.

In some instances, modest thermal energy gains might be utilized to elevate interior temperatures, thereby depressing RH without necessarily changing the concentration of atmospheric moisture vapor.

Simple systems interventions may be utilized to supplement and enhance passive and active measures as hybrid alternatives to full air-conditioning. Examples are: powered ventilation or exhaust to augment natural ventilation rates (Padfield and Larsen 2005), and high-efficiency dehumidification to trim the upper limits of the RH range (these typically add sensible heat to the space as a by-product of the dehumidification process).

The implementation of passive strategies is relatively straightforward, since once in place, these measures must merely be maintained but not necessarily activated. In contrast, the implementation of active strategies requires operational controls or protocols, since these measures must be activated in response to changing external or internal conditions. For example, if window shutters or shades are used to manage solar heat gain, the position of a window shutter or blind might need to be adjusted throughout the day to reduce solar heat gain while maintaining an acceptable level of interior light and ventilation through the window opening. For optimum benefit, these operational responses cannot be random or intuitive. Therefore, implementation of active strategies needs to be guided by specific *operating protocols* or *operating regimens*.

Operating protocols or regimens consist of prescribed actions to be taken by the building occupant in response to a set of circumstances or interior/exterior conditions, in order to optimize mediation of the exterior climate by the building and provide an interior environment that meets stated objectives for comfort and/or conservation. Examples include:

- *Routine instructions* of predictable actions, undertaken on a daily or seasonal basis, based on historic averages of climate data and building response and informed by occupant observations. An example would be, "Keep the east window sash open between 0700 and 1500 between 01 May and 21 September, except when raining."
- *Real-time regimens* of actions, undertaken on an hourly, daily, or seasonal interval, based on historic climate data and building response, informed by real-time data on specific exterior and interior conditions, supplemented by occupant observations. An example might be, "Open the east windows when the exterior dew point temperature is 2°C lower than the interior dew point between 01 May and 21 September."

Routine instructions are effective for macroadjustments in building performance, with less frequent occupant intervention, whereas real-time regimens allow finer-grained adjustments but with more frequent occupant intervention. Real-time analysis of data trends—not just of present conditions—informs anticipatory actions by the building operator rather than reactive interventions to undesirable conditions. Anticipatory management is crucial if environmental objectives for collections conservation include reduction of temperature and/or RH fluctuations. Successful execution of anticipatory actions by the building operator requires "good feedback information on performance and good knowledge of the purpose and function of systems" (Bordass and Leaman 1997).

In some instances, reactive intervention by the building operator may be sufficient. In either instance, anticipatory or reactive, design of the environmental management strategy should take into considerations the building operator. To this end, Bordass and Leaman advise the following for the successful manageability of buildings by occupants:

- "The fewer demands a building makes on management services, the better.
- "Passive is better than active. Make sure that things which are designed to operate in the background do so properly.
- "Things which need changing or looking after should be usable, preferably by those who are most directly concerned with them. Responses should be rapid and understandable.
- "Simple is better than complex, but when complexity is necessary, try to package and isolate it wherever possible, and provide simple interfaces.
- "Cater where possible [to] people's preference ranges rather than averages or norms. Try to foresee risky situations and consider how people may compensate.
- "Potential failure paths should be identified and if possible avoided; if not, appropriate indicators should be monitored to help identify, and deal with, incipient problems.
- "Try to assess risk cost-effectively, so that resources are spent realistically on avoiding the costliest and most risky events.
- "Beware unsubstantiated promises of 'flexibility' which may bring unforeseen management costs.
- "Recognize that all situations are subject to constraints, which will reveal themselves sooner or later.
- "Remember that designers are not users, although they often think they are!" (Bordass and Leaman 1997)

In addition to the above, it will be critical to train the building occupants in the use, operation, and maintenance of the selective environmental features, as well as in the execution of the operational protocols or regimens. Information for occupant training and use should be clearly documented and readily retrievable.

Potential Issues with Reinstating the Heritage Building as a Passive and Active Climate Moderator

In heritage buildings, the operable features and devices of the building and building envelope may be multifunctional. For example, window shutters may provide security and privacy, control incoming light and solar heat gain, and reduce air and moisture exchange with the exterior. An operable window sash can regulate natural ventilation when open, but it must be closed to control dust and particulates or unauthorized entry by people. Window and door screens may be historically anachronistic for certain interpretive periods, but they may be needed to reduce insect, avian, and pest entry through open windows.

The potential for conflicting outcomes must be explored and resolved in the development of strategies for using the heritage building for passive and active interior environmental management (case study 1a).

Case Study 1a: Drayton Hall

In response to observable deterioration and loss of interior architectural finishes, conservation studies and environmental monitoring were conducted in 1996–97 and concluded that "several environmental factors produce stress in the paint . . . Condensation, rapid changes in temperature and RH, and high ultraviolet light levels were found to be a result of the museum's operation" (Mills and Fore 2000). Mills and Fore recommended that the mid-nineteenth-century blinds be reinstalled to reduce interior light levels, that the normal operational procedure of opening doors in early morning be modified to a later time to reduce the influx of high exterior atmospheric moisture, and that source moisture control for roof runoff be implemented. Mills and Fore also recommended that the environmental monitoring system be retained to provide real-time information for operating windows and doors. The blinds were reinstalled, but the monitoring system was removed.

In 2001, with funding from the Getty Grant Program and Save America's Treasures, Watson and Henry Associates designed and installed a monitoring system to advise the museum staff in real time as to the operation of the windows and doors, in order to manage interior conditions and slow deterioration of the interior finishes. The system collects interior and exterior environmental data and analyzes the data using an algorithm, resulting in a real-time advisory to museum staff as to whether the building should be ventilated by operating the windows and doors (Henry and Switala-Elmhurst [2001]).

Keeping the exterior doors closed in the early morning hours, as recommended by Mills and Fore and as implemented by the Watson and Henry Associates operating algorithm, results in low ambient light levels in certain spaces, particularly the stair hall. Closing exterior doors during rainfall also reduces interior light levels throughout the building. Tour guides object to the lower ambient light levels, and there are interpretive objections to introducing artificial light into selected light-deficient spaces. One option is to adjust the tour schedule seasonally and to open the building according to natural light levels and the ambient interior light, but this strategy has revenue implications and complicates the posting of predicable operating hours. Currently, the operating advisory capacity of the monitoring system is not used. At present, the doors are opened according to a time schedule—they are opened somewhat later than they were when Mills and Fore conducted their monitoring but earlier than would have been directed by the Watson and Henry Associates advisory system. As a result, the full efficacy of the recommended environmental management strategy for reducing the influx of atmospheric moisture in the morning or during rainfall remains unrealized.

The Necessity of Considering Alternatives to Air-Conditioning

Based on the above, it is clear that environmental management strategies that use the heritage building for passive and active moderation are not necessarily easier to design and implement than conventional mechanized approaches of environmental control using air-conditioning. In fact, the former requires in-depth knowledge of the hygrothermic performance attributes of a building, as well as the negotiated resolution of a number of potentially conflicting objectives, while the latter may be arrived at through the application of comparatively straightforward design templates.

If design is not simplified, and operation is not automatic, what is the incentive for a heritage building steward to opt for the environmental management strategy, as opposed to control? The answer may lie in cultural stewardship in the global sense.

In February 2007, the Intergovernmental Panel on Climate Change (IPCC) issued its fourth assessment on the future of global climate, *Climate Change 2007: The Physical Science Basis* (www.ipcc.ch). The IPCC, an international network of leading climate scientists, concluded that the link between human activity and increased global warming is "unequivocal." The report states that of the human activities that contribute to global warming, the largest influence is the generation of carbon compound emissions from fossil fuels combustion for transportation, for electricity generation for uses such as lighting and cooling, and for heating.

The IPCC report identifies several future climate trends in the twenty-first century, all of which are directly related to human activity:

- warmer and fewer cold days and nights over most land areas;
- warmer and more frequent hot days and nights over most land areas;
- more frequent warm spells or heat waves over most land areas;
- more frequent heavy rainfalls over most land areas;
- increased drought in areas affected;
- increased intense tropical cyclone activity;
- increased incidence of extreme high sea level.

The report also notes a future increase in atmospheric moisture vapor; depending on air temperature, this change may result in increased RH.

As stewards of cultural heritage, we cannot afford to look at this global situation as merely a problem for environmental scientists, industry, or government. Climate change and global warming are of great importance to cultural heritage stewards in two respects: in their impact on cultural heritage, and in the ways that mitigating this impact contributes to global warming.

First, consider the potential impact of climate change on the conservation of cultural heritage—particularly of cultural landscapes and fixed property, such as buildings. In 2005 the Centre for Sustainable Heritage (CSH) at University College London released its milestone study *Climate Change and the Historic Environment*. Based on 2002 projections for trends in climate change in the United Kingdom, the CSH evaluated the possible consequences of those projected trends on UK cultural heritage resources. The implications are sobering.

Rising sea levels are a real concern. Less obvious climatic factors threaten as well. Changes in the extrema, range, intensity, and frequency of climate variables such as temperature, atmospheric moisture, wind, and rainfall will lead to acceleration of existing deterioration mechanisms or to the initiation of new mechanisms. Buildings, the first line of defense for the collections, may lack the capacity to resist higher wind loads. The rainwater systems of buildings and sites may be undersized for more intense, but less frequent, rainfalls, leading to excess surface water or even flooding. Changes or variations in soil moisture can change soil volume, leading to stresses and cracking in foundations. Some of the problems projected by the CSH study are already being experienced in the United Kingdom and Europe. While the study focuses on the United Kingdom, it provides a sense of the type and scale of effects that might be experienced by cultural heritage resources elsewhere.

The costs of mitigating the risks or of repairing the resultant damage from these new climate factors will be great. In the case of catastrophic climatic events, there will be cultural heritage losses that cannot be restored, as in the recent devastation at New Orleans and the U.S. Gulf Coast. In such circumstances, given the larger societal priorities, cultural heritage needs are not likely to be adequately funded.

In addition to the direct effect of climate change on cultural heritage, we must be aware of how our actions in cultural heritage conservation contribute to the generation of the carbon compounds that lead to global warming. For example, in the United States, it is estimated that air-conditioning accounts for up to 20 percent of our electrical power use, 71 percent of which is generated by burning coal, petroleum, and natural gas. The energy cost of close artificial control of interior environments is higher than for more relaxed control, especially with respect to RH. Therefore, tight performance targets for artificial interior environments for collections of all types, significance, and value add to the electrical power and fossil fuel consumption for buildings and sites. Unless our systems are powered by carbon-neutral energy sources, such as wind or photovoltaic power systems, we are contributing to the primary factor in global warming. As Pogo, the cartoon strip philosopher, commented on the state of the environment in 1971, "We have met the enemy and he is us."

Measures for protecting cultural heritage must not contribute to the exacerbation of the very climatic effects that can threaten their longevity. Such measures set up a positive feedback loop that intensifies, rather than attenuates, the conservation problem and its costs. As global warming increases the extrema and range of exterior conditions such as temperature and RH, we cannot respond by tightening control of the interior environment with higher-capacity mechanical systems that consume more energy and emit more carbon compounds.

Our stewardship responsibilities to future generations are not limited to the protection of material evidence of our significant objects, buildings, and landscapes. Our unwritten intergenerational compact requires that we transmit this cultural legacy within an environmental, economic, and social context that allows for viable stewardship in the future. Adhering to such a compact is a fundamental tenet of sustainability.

A sustainable approach to cultural heritage is an overarching philosophy that should permeate our thoughts and actions. Environmental management is one aspect of the implementation of this philosophy, and it is a singularly important one because of its consequences for cultural heritage conservation, energy consumption, and capital and operating costs.

Conclusion

In the twentieth century, air-conditioning made the prospect of four-season environmental control a reality, influencing not only building design but perceptions and technical definitions of occupant comfort. Revisiting our environmental management strategies for preventive conservation in the light of a sustainability mandate is critical. Environmental management, particularly air-conditioning, is a large component in the energy consumption and carbon emissions at our institutions and sites. We can reduce the potentially adverse impact of our environmental management strategies if we:

- adjust our performance criteria for conservation environments by taking into account the robust qualities and vulnerabilities of the collections against the exterior environmental threats specific to the location;
- reduce carbon emissions (and operating costs) without necessarily reinvesting in air-conditioning systems by implementing broader criteria for interior environmental control;
- account for, and fully credit, the passive and operable features of the building that can moderate the environment and afford protection for the contents and collections, and rely on these features rather than on mechanical systems to the extent practical;
- improve or enhance the inherent environmental performance qualities of the building envelope;
- evaluate new or alternative environmental management strategies in lieu of four-season mechanical systems for environmental control.

As we undertake these new approaches to environmental management, it is important that we inform and educate the public about the need for our action and the ways in which we are addressing that need.

In striking a balance between collections stewardship and environmental responsibility, we will undoubtedly face competing needs that challenge our past assumptions and practice. However, it is likely that we will also discover new opportunities to enrich our interpretation of both collections and heritage buildings.

Author Biography

Michael C. Henry, principal engineer and architect, Watson and Henry Associates, Bridgeton, New Jersey, is a registered engineer and registered architect. He holds a bachelor of science in mechanical engineering from the University of Houston and a master of science in engineering from the University of Pennsylvania. Since 1984 he has specialized in historic preservation and environmental issues of historic buildings housing collections. He teaches in the Graduate

Program in Historic Preservation at the University of Pennsylvania. He was 2005–06 Fulbright Distinguished Scholar at the Centre for Sustainable Heritage, University College London; the research undertaken there has informed this paper.

Figures

Figure 1

Spreading the word: Beat the heat. Photo: Michael C. Henry, Watson and Henry Associates.

Figure 2

Drayton Hall. Photo: Michael C. Henry, Watson and Henry Associates.

Figure 3

Louvered and paneled shutters in Drayton Hall. Photo: Michael C. Henry, Watson and Henry Associates.

Figure 4

The Pitot House. Photo: Penelope S. Watson, Watson and Henry Associates.

Figure 5

Exterior gallery of the Pitot House. Photo: Michael C. Henry, Watson and Henry Associates.

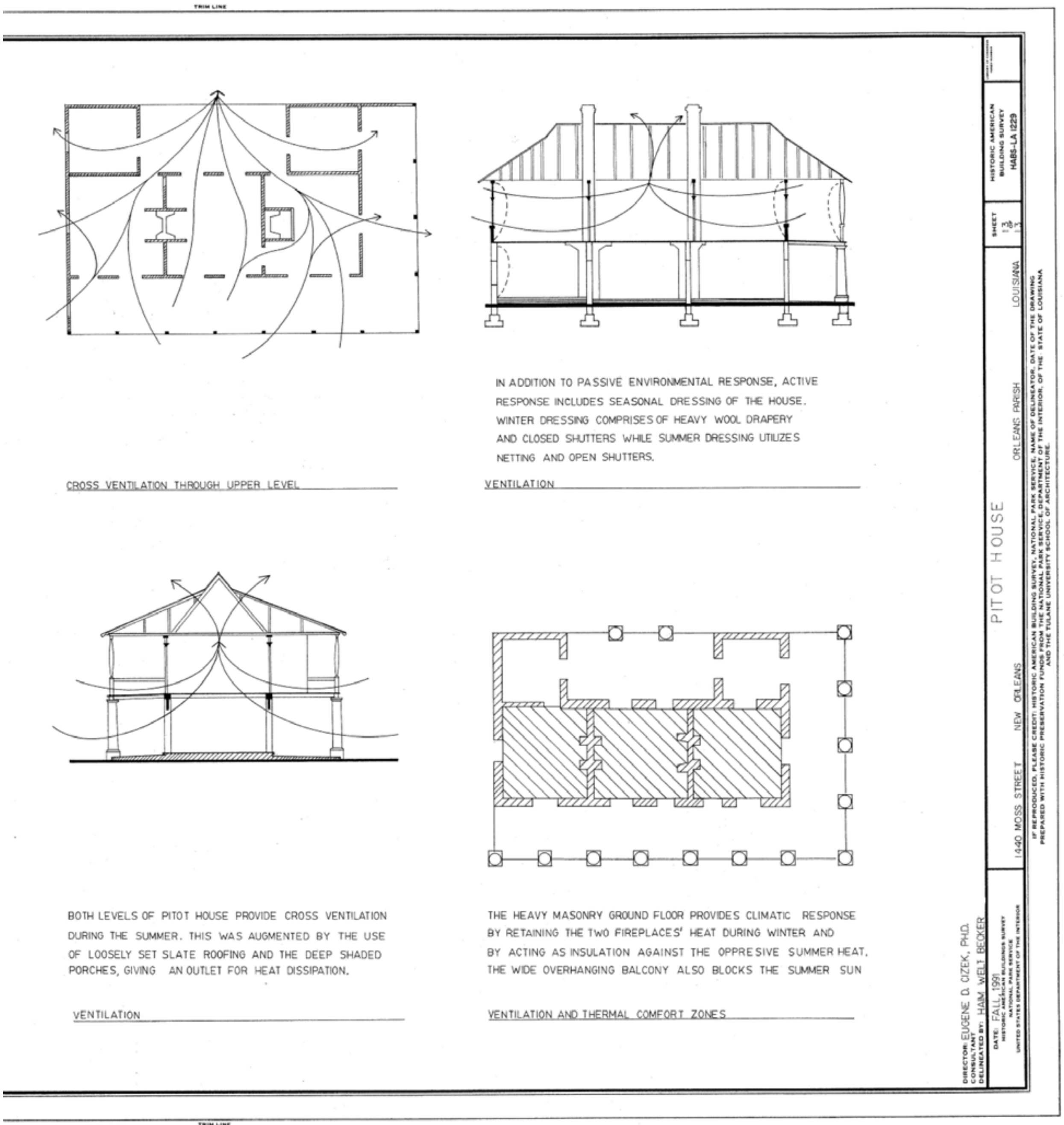

Figure 6

Historic American Building Survey drawing of the ventilation of the Pitot House. Drawing: Library of Congress, Prints and Photographs Division, Historic American Buildings Survey, HABS LA-1229.

Figure 7

The Gibson House ventilation and light shaft viewed from the main hall below. Photo: Michael C. Henry, Watson and Henry Associates.

Figure 8

The Gibson House ventilation and light shaft viewed from the shaft interior. Photo: Michael C. Henry, Watson and Henry Associates.

Figure 9

The Gibson House ventilation and light shaft with thermometer, seen from the bathroom.

Photo: Michael C. Henry, Watson and Henry Associates.

References

ASHRAE [American Society of Heating, Refrigerating, and Air-Conditioning Engineers]. 2003. Museums, libraries and archives. Chap. 21 in *2003 ASHRAE Handbook: Heating, Ventilating, and Air-Conditioning Applications I-P Edition*, 21.1–21.16. Atlanta: ASHRAE.

———. 2005. Thermal comfort. Chap. 8 in *2005 ASHRAE Handbook: Fundamentals*, 8.1–8.29. Atlanta: ASHRAE.

Bordass, W., and A. Leaman. 1997. Design for manageability: Unmanageable complexity is a major source of chronic problems in building performance. *Building Research and Information* 25, no. 3: 148–57.

Cook, Jeffrey. [2001.] Openness as a factor of comfort: Architectural choices from experience, not experiments. Paper presented at "Cooling Frontiers: The Advanced Edge of Cooling Research and Applications in the Built Environment: International Symposium Held 4–7 October 2001, Tempe, Arizona." College of Architecture and Environmental Design, Arizona State University.

Cooper, Gail. 1998. *Air-Conditioning America: Engineers and the Controlled Environment, 1900–1960.* Johns Hopkins Studies in the History of Technology, vol. 23. Baltimore: Johns Hopkins University Press.

Crowley, John E. 2001. *The Invention of Comfort: Sensibilities and Design in Early Modern Britain and Early America*. Baltimore: Johns Hopkins University Press.

Henry, Michael C., and Katherine Switala-Elmhurst. [2001.] Climate monitoring and management system for Drayton Hall: Project design document. Watson and Henry Associates, Bridgeton, NJ, for the National Trust for Historic Preservation, Washington DC.

Louw, Hentie, and Robert Crayford. 1999. A constructional history of the sash-window, c. 1670–c. 1725 (Part 2). *Architectural History* 42: 173–239.

Mills, Michael J., and George Fore. 2000. Environmental monitoring and conservation study of Drayton Hall in Charleston, South Carolina. *APT Bulletin* 31, nos. 2–3: 63–70.

Padfield, Tim, and Poul Klenz Larsen. 2005. Low-energy air conditioning of archives. In *ICOM Committee for Conservation: 14th Triennial Meeting, The Hague, 12–16 September 2005: Preprints,* ed. Isabelle Sourbès-Verger, 677–80. London: James and James, Earthscan. Available at http://www.padfield.org/tim/cfys/arnemag/arnemag_nrwch.pdf.

Roaf, Susan, David Crichton, and F. Nicol. 2005. *Adapting Buildings and Cities for Climate Change: A 21st Century Survival Guide*. Oxford: Elsevier Architectural Press.