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Why do we keep doing this?
An argument for informed environmental assessments

David Bittermann, AIA

ABSTRACT

There is too often a tendency to presume that particular environments can be created within historic house museums simply by “tightening up” the envelope and installing sophisticated mechanical equipment. This approach is unsustainable from many standpoints. Extensive mechanical systems can be intrusive or damaging to historic fabric, expensive to operate and maintain (to the point of overwhelming the financial capacity of institutions), and inadvertently hasten climate change. Careful consideration should be given to the basis for expected environments to be maintained with respect to both the actual needs of the collections and the capacity of the envelope to contain them. Only with a thorough understanding of both, gained through survey, testing, and monitoring, can mechanical systems be appropriately designed. In so doing, one must be willing to use to fullest advantage the structure’s inherent historical methods of environmental modulation, and to creatively think “outside the box” when applying modern mechanical systems to fulfill the need.

A CAUTIONARY TALE

Imagine this all-too-familiar scenario: a nationally significant historic house museum is due for a major mechanical system upgrade. Funds are raised, engineers are engaged, and the project team provides the following marching orders: “We need a system that will maintain optimal conditions for our valued collections.”

The house had originally been built with a gravity hot-air system, with its characteristic network of ducts emanating from a central coal-fired furnace like the tentacles of an octopus (Figure 1). Eventually the furnace was replaced with an oil-fired unit, and blowers were added to convert to forced air for improved distribution and control. Finally, the ducts in the cellar were reconfigured to create different heating zones.

Having all happened decades prior to the house becoming a museum, this was perceived by the project team as terribly substandard. No doubt the house had never been conceived of as a museum, neither in its original design nor in its subsequent upgrades. As with all residential architecture, it was built and then altered in accordance with the standards of aesthetics, functionality, and comfort that were characteristic of its time.

Since becoming a museum, however, windows were sealed shut to facilitate dust control and filtering of ultraviolet radiation and visible light. Heating was applied generously in the winter for the comfort of staff and visitors alike. Window air conditioners were installed because occupants could not abide the summertime heat buildup in a closed building. These measures notwithstanding, conditions seem less than optimal. The project team has noticed subtle damages to the collections, as veneers are detaching, cracks in various objects are opening, and metals are showing signs of corrosion. Moreover, the interior has begun to smell musty, and mold has been noticed on books on shelves and on surfaces behind furniture.

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These anecdotes are related by the project team to the engineers, who, in turn, inquire what conditions would be required to be maintained in order to prevent the damages that have been noted. They are met with the following response: "Museum standards call for maintaining relative humidity at 50%, with short-term fluctuations not exceeding +/– 5% RH, and temperature at 70 degrees F, with short-term fluctuations not exceeding +/– 5 degrees F."

But where did these numbers come from? And what materials are they referencing? The most rigorous notion of 50% RH and 70 degrees F temperature to be maintained year-round are of apocryphal origin, and numerous articles have already been written on the evolution of that belief. More recent approaches have allowed the concept of seasonal drifts progressing at a gradual controlled rate. Discussions of these and other moderations have been publicized by the American Institute for Conservation of Historic and Artistic Works (AIC), Canadian Conservation Institute, the Getty Conservation Institute, and others,[1] including the National Park Service Museum Handbook;[2] however, the original notion, due to its simple straightforward absolutism, presents an easy fallback when more nuanced and studied approaches to the standards seem too confusing.

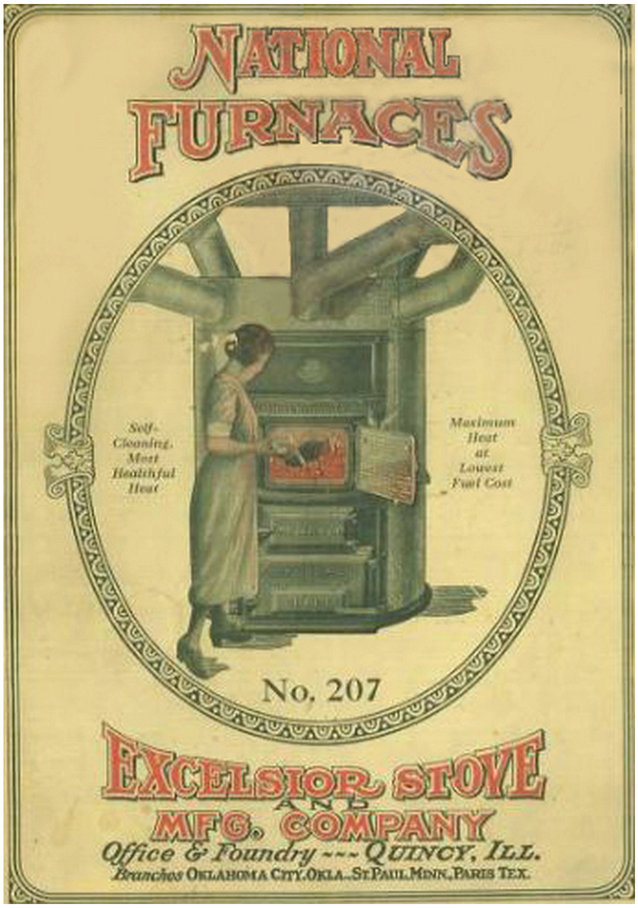


FIGURE 1. Typical gravity warm air furnace. APTI BUILDING TECHNOLOGY HERITAGE LIBRARY

The engineers, having little patience for nuance, accept the initially offered standards as the mandate to design a new system that hypothetically will be able to maintain them. And so, the problems begin. The resultant design retains much of the original ductwork, but little else. The furnace is replaced with a boiler that provides hot water to a heating (and possibly reheat) coil in an air handler.

The house is presumed to be quite leaky due to anecdotal evidence, and the blowers are sized accordingly to provide high enough air delivery rates (through the old ducts and registers) that are presumed necessary to maintain the desired conditions.

The resulting calculated rates far exceed anything the house has experienced in its past. Supply registers sound like jet engines, or at least are loud enough that docents have difficulty being heard by visitors. Draperies across the room billow in the breeze. Docents and curatorial staff cannot abide the effects of the "blizzards," and either attempt to override the controls or block the supply registers, in either case inadvertently negating the intent of the upgrade or causing other deleterious effects.

The situation is even worse when centralized cooling, dehumidification, or humidification are introduced into the equation. In the case of cooling, setpoints are often set too low (for human comfort), inadvertently causing condensation in uninsulated historic ductwork, with attendant corrosion, dripping, and mold outbreaks. Centralized dehumidification often relies on aggressive cooling followed by reheat; requiring sophisticated sensors and controls. It can be highly energy consumptive and demanding of rigorous maintenance. Centralized humidification can be even more problematic, placing even greater demands on maintenance. Moreover, these systems, when not adequately maintained, have the capacity to quickly wreak far more damage to collections than they could have prevented under ideal operating conditions.

Until recently, the impact on climate change rarely factored into the decision-making process. Rather, the focus was on how tightly the conditions could be controlled, as well as the construction and operating costs (especially energy costs) attendant with doing that. Energy costs might be evaluated from the standpoint of fuel source (oil versus natural gas or propane) or equipment efficiency ratings, but would more often than not be secondary to tightness of control.

How do we get into these predicaments? Often this can happen when too much credence is given anecdotal evidence.

ASKING THE RIGHT QUESTIONS

How do we get into these predicaments? Often this can happen when too much credence is given anecdotal evidence, or when collections management plans and condition surveys are too narrowly focused. If important contextual information is overlooked, shaky conclusions can result. With respect to environmental concerns, the contextual information should at a minimum include the following:

1. What is the variability in objects comprising the collection? Different classes of objects prefer different environments.
2. How long has an object lived in its environment, and what is that environment?
3. Has an object acclimated to the environment, and in what way? Are any observed distresses cyclic or progressive? What are the perceived rates of loss?
4. What is the condition of the largest piece of the collection—that is, the historic structure itself?
5. And most important: what environment is the historic structure able to achieve and contain without significant loss of its own integrity?

While the last two questions may seem surprising to many, their importance was codified in the 1991 *New Orleans Charter for Joint Preservation of Historic Structures and Artifacts*, adopted by AIC and the Association for Preservation Technology International.[3] Consideration of the structure as part of the collection casts the question of environmental control in a completely different light. This is not to say that the historic structure is more important than the collections it contains; rather, it is often the limiting factor regarding which particular pieces of the collection can be happily contained within.

A lack of thoughtful answers to these questions in particular is what can lead to the aforementioned shaky conclusions. And until recently, these questions were not routinely asked. Rather, the logic would progress in three simple steps: (1) several parts of the collection are exhibiting significant distress owing to perceived deficiencies of their respective environments; (2) as proper stewards of the collection we must provide optimal environments; and (3) the best way to accomplish this is to design and install a full-blown new mechanical system providing heating, cooling, humidification, and dehumidification.

Countless project statements in funding applications have said essentially this and no more: "It's badly broken—it's incumbent upon us to fix it—here's what we'll do to fix it." Such project statements often must specify the solutions, no matter how vague or ill-considered, if they are to effectively compete for funding. The more dire the problem and the more certain the remedy, the more likely the funding. Nuance does not play well here. When the funding is eventually obtained and the engineers called in, among the first questions they might ask: "Tell us what conditions you need to maintain?" And the stage is set for the opening scenario.

A BROADLY BASED ASSESSMENT

Answering the above questions carefully is essential to obtaining appropriately scaled and sustainable solutions to these complex problems. The Getty Conservation Institute in particular has been on the forefront of promoting this new way of thinking. It has facilitated studies, disseminated numerous articles, and provided many training sessions to engage the broader curatorial, conservation, engineering, and museum management communities alike.[4] Forwarding the cause, the Historic Architecture, Conservation, and Engineering Center (HACE) in the National Park Service North Atlantic–Appalachian Region is developing ways to put these concepts into practice within the Region's historic structures.

To this end, HACE has begun engaging Architectural and Engineering (AE) services to perform comprehensive environmental assessments at various museum house properties. A typical scope of work for such an assessment might include the following:

1. Review all prior relevant documentation concerning the building and collections. This would include anything pertaining to the evolution, condition, current configuration, and relevant treatments applied to the building envelope. It would also include collection management plans, surveys, and collection condition reports, as well as pertinent treatment reports on critical pieces. Finally, it would include documentation of the building's mechanical, electrical, and plumbing systems (MEP), including histories of problems, contract documents for prior upgrades, and operation and maintenance (O&M) manuals.
2. Review all prior relevant environmental data. Usually, the available data are limited to indoor temperature and relative humidity readings in various spaces, although exterior data, if collected, are also of importance.
3. Perform a complete survey of the exterior envelope, focusing on conditions that would directly affect the environments contained within, as documented by the previously collected data.
4. Identify those items in the collection representative of their respective object classes and that can be considered the "canaries in the coal mine" in that they provide early warning of harmful conditions.
5. Based on the above, propose a regimen of new data collection to be conducted over the coming year (a full four-season profile being essential to the analysis). Data should include, at a minimum; indoor temperature and relative humidity (with calculated dew points) in representative locations throughout the structure, and especially in rooms containing the respective "canaries." Data should also include exterior temperature, relative humidity (with calculated dew points), wind speed and direction, barometric pressure, and rainfall (Figure 2). Data should include differential pressures (in inches water column) between mechanical spaces and other spaces, and between indoors and outdoors (Figure 3). If the mechanical system includes cooling, humidification, and/or dehumidification via a ducted system, then data would need to include temperature and relative humidity (with calculated dew points) at supply air registers in critical spaces (Figure 4) and at each air handler discharge (Figure 5). Finally, various air quality monitoring may be indicated, including indoor CO^2 levels in ppm (Figure 6) as well as indoor and outdoor particulate levels (PM2.5 AQI) (Figures 7 and 8).
6. Various testing protocols are also important to perform. These include blower door tests (Figure 9) with infrared thermography (Figure 10) to evaluate air infiltration extents and pathways, and, in the case of systems utilizing ducted air delivery,

FIGURE 2. Weather station at Edison's Glenmont. DAVID BITTERMANN

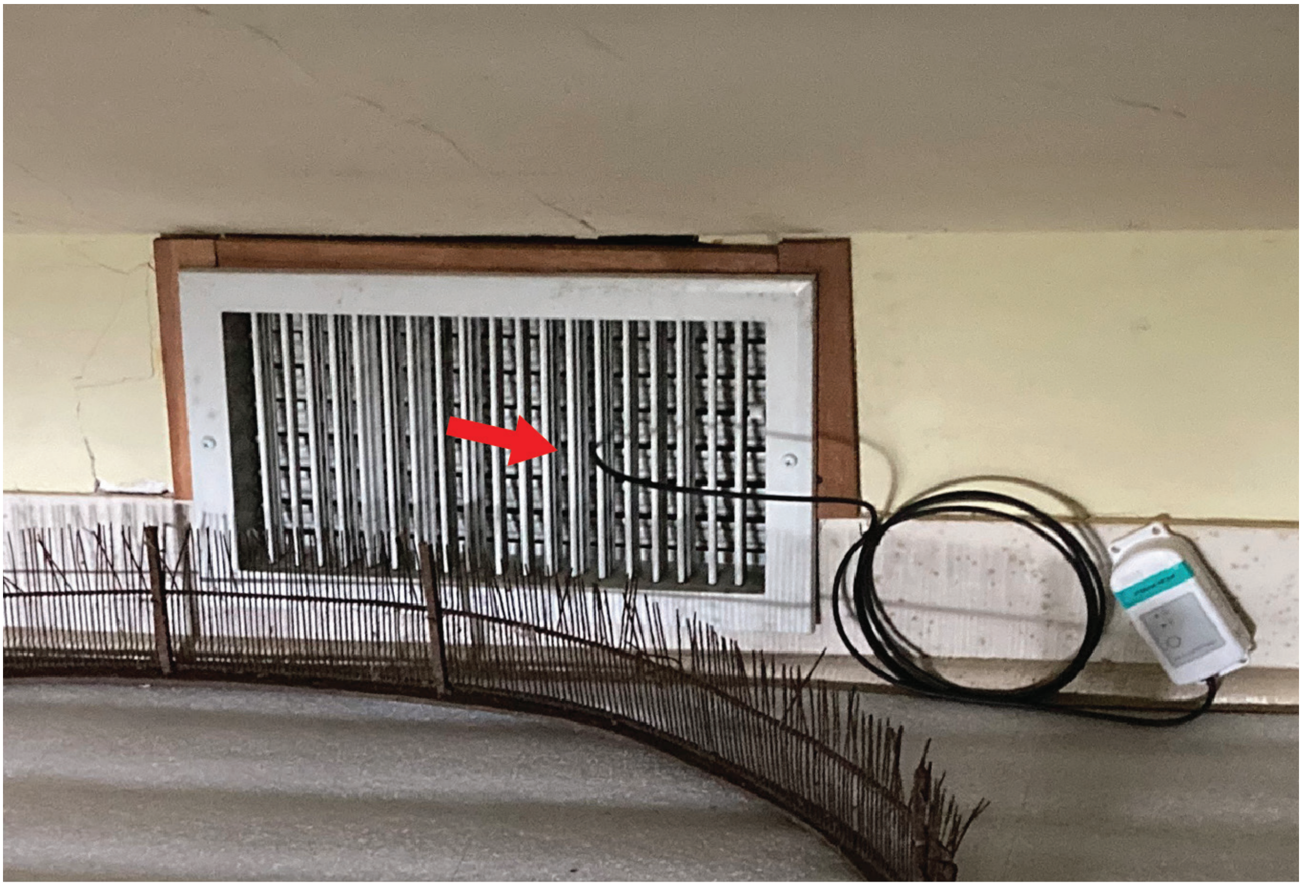


FIGURE 3 (above). Monitoring differential pressure between interior and exterior. **FIGURE 4** (below). Monitoring temperature and relative humidity at supply register. DAVID BITTERMANN

FIGURE 5 (left). Monitoring temperature and relative humidity at air handler supply duct. FIGURE 6 (right). CO^2 **monitor.** DAVID BITTERMANN

static pressures at the air handlers (Figure 11) and discharge rates at each supply register (Figure 12), along with associated sound levels. These testing results in particular provide important baseline information against which to compare future results after any system modifications.

7. Other testing might be more specific to existing systems encountered, and could include analyzing the operating characteristics of boilers, pumps, chillers, condensers, compressors, fan coil units, and controls, etc., much as what might be normally performed in a systems commissioning exercise.
8. Finally, it may be necessary to collect information on energy consumption that is more revealing than just looking at the utility bills. Various devices routinely used in heating, ventilation, and air conditioning (HVAC) control systems can be engaged to detect when or at what rate a piece of equipment is running, and to send that information to a data logger input.

What is the point of collecting all this information? There are several reasons. To begin with, it can enable discernment as to the types and levels of distress that might be observed in the various classes of collections. In conjunction with the testing results, the data can also provide insight as to what conditions the mechanical system is trying maintain, and the degree of success at achieving those conditions. The data also help to establish the extent to which the conditions result from the building envelope characteristics as opposed to those of the mechanical system. Although both play a role, the important point is that building envelopes are limited in the quality of environments they are able to contain, based not only on their condition but on their configurational characteristics. While the former can and should be corrected if deficient, the latter are more difficult and sometimes not possible to change due to adverse impacts on historical integrity.

Bottom line: there are limits to what a historic building envelope can contain and attempts to override these limits via more intensive mechanical systems can lead to unintended adverse consequences for collections and buildings alike.

(top row, l–r) **FIGURE 7.** Indoor particulate monitor. **FIGURE 8.** Outdoor particulate monitor. DAVID BITTERMANN

(bottom row) **FIGURE 9.** Blower door testing at Lindenwald, Martin Van Buren National Historic Site (left) and at Sagamore Hill National Historic Site (right). MAVA: DAVID BITTERMANN; SAHI: STEVEN WEINTRAUB, ART PRESERVATION SERVICES

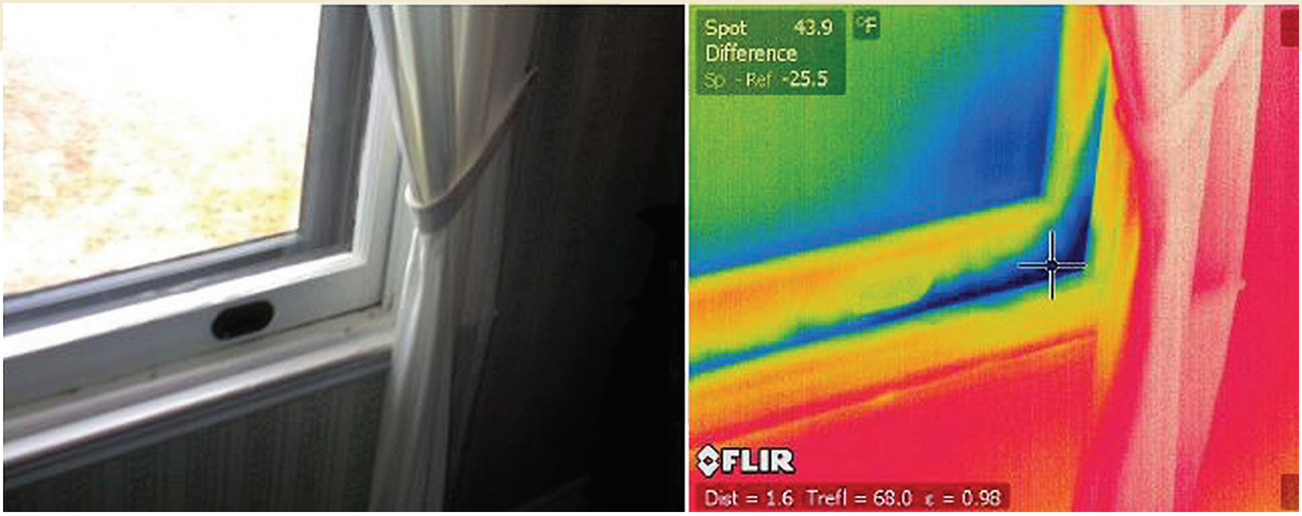


FIGURE 10 (above). Thermal imaging at Sagamore Hill. STEVEN WEINTRAUB, ART PRESERVATION SERVICES
FIGURE 11 (below). Measuring static pressure and airflow at air handler. DAVID BITTERMANN

FIGURE 12 (left). Measuring discharge rates with anemometer and flow hood (right). LEFT: DAVID BITTERMANN RIGHT: MARGARET BREUKER, HACE

DATA QUALITY/CONSISTENCY

To be truly useful, monitoring must be performed in a disciplined and thought-out manner. For optimal analysis, data should be measured and collected at no greater than 15-minute intervals, and all data sets must carry identical time stamps. That is to say, logging sessions must be commenced at exactly the same instant throughout if it is desired to compare data sets from each device.

Depending on what circumstances or parameters are of concern, some data sets may demand more frequent collection intervals (such as those measuring differential pressures) or may respond to specific triggers (rain gauges).

Data should be locally sourced to the greatest extent possible. The external conditions that a particular structure experiences are not the conditions experienced at an airport weather station 30 miles away.

A concurrent log of events should be kept, noting dates and times of unusual or significant operational events, such as seasonal changeovers, setpoint changes, systems malfunctions, beginnings or endings of interpretive seasons, etc.

TYPES OF ANALYSES

Scatter plots on psychrometric charts: Plotting data on a psychrometric chart, demarcating specific spaces and seasons, with respect to generalized parameters determined by building type and construction.[5] Although "scatter plots" have often been used to evaluate relative tightness of data, superimposing these on a psychrometric chart (Figure 13) can reveal what portions of the data fall within the desired parameters, and when.[6]

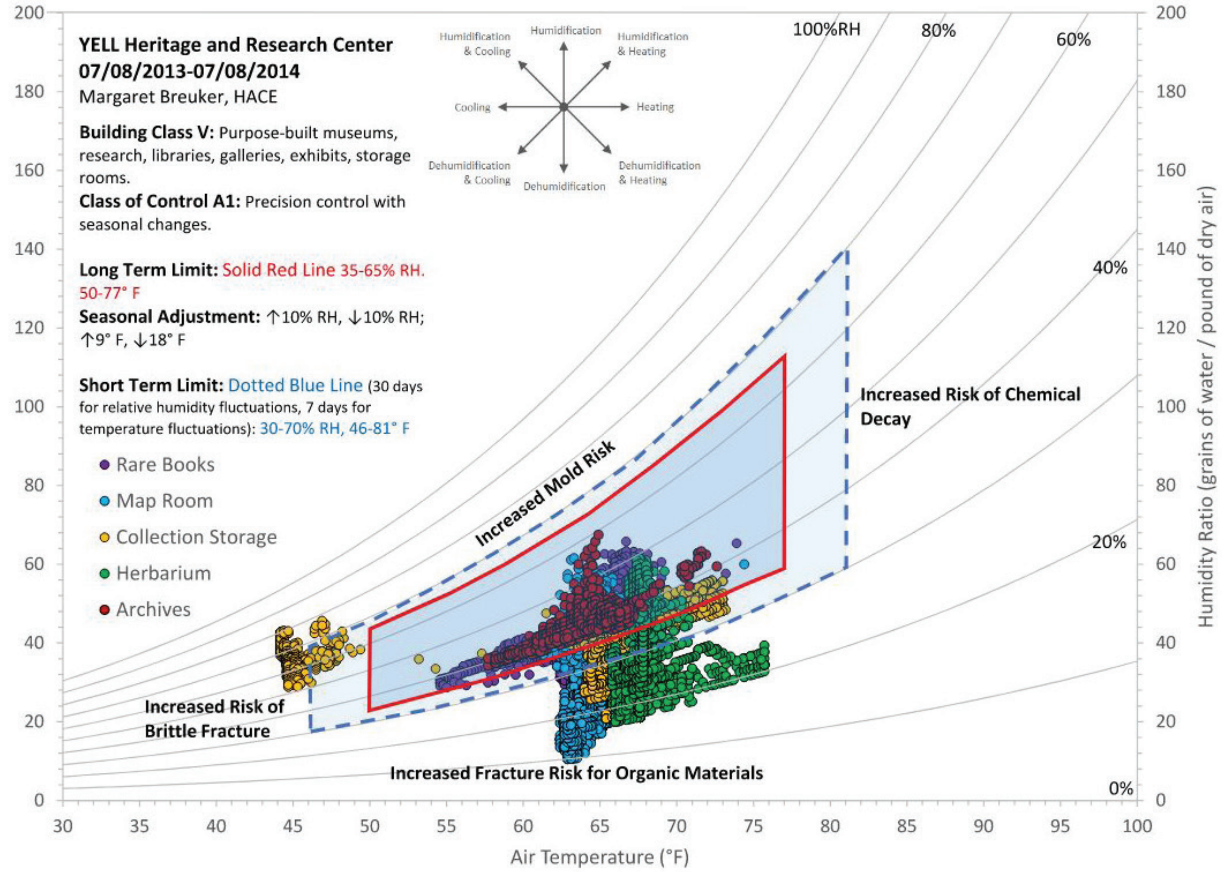


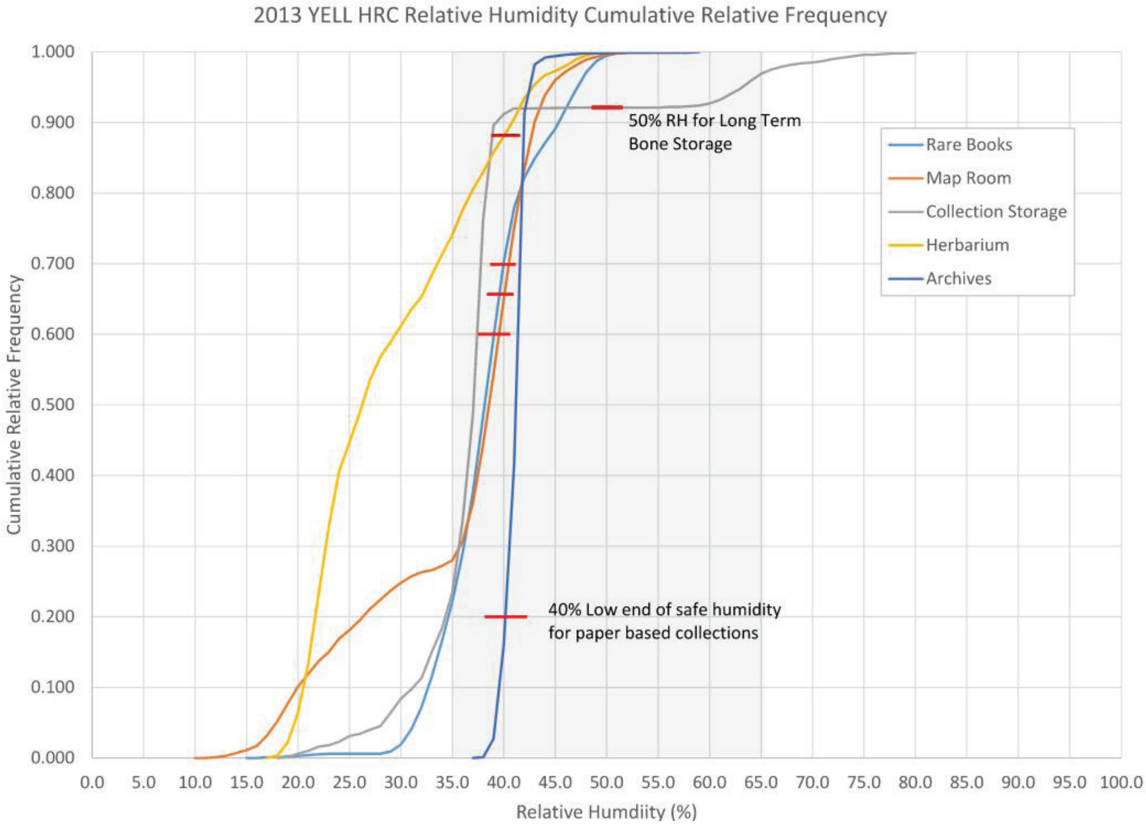
FIGURE 13. Temperature and relative humidity data plotted on psychrometric chart. MARGARET BREUKER, HACE

Cumulative relative frequencies: These indicate what percentage of measured conditions fall within the overall desired parameters. Appearing as "S" curves (Figure 14), the plot affixes the measured condition on the horizontal axis and the frequency of occurrence (as a percentage of the overall data set) on the vertical axis.[7]

Time series, with 7-day and 24-hour running averages: While straight time series (measured parameter represented on a linear time scale) are the most commonly available packaged graph from commercial data loggers, superimposing calculated running averages (Figure 15) for 7-day and 24-hour durations (or other durations of interest) are more instructive in understanding how changes in measured parameters actually affect various classes of objects.[8]

Statistical plots and wrap-ups: Many data logger software packages provide statistical plotting or wrap-up capabilities, including Maximum, Minimum, Average, and Standard Deviation for any given monitored parameter. Getty tools provide Average, Standard Deviation, Max, Q3 (75th percentile), Median, and Q1 (25th percentile).[9] Image Permanence Institute (IPI) tools further ascribe specific meanings, with Preservation Index (PI) and Time-Weighted Preservation Index (TWPI), Mold Risk Factor (MRF), Maximum and Minimum Equilibrium Moisture Content (MaxEMC, MinEMC), and Percent Dimensional Change (%DC).[10]

What-if plots: One can overlay predictive plots onto actual measured conditions plots to determine what would have been the impact on measured conditions if one of the parameters (temperature, relative humidity, or dew point) were tightly controlled to achieve a specific goal (Figure 16). For example, in conservation heating, one could look at the potential effect of modulating the application of heat in service of avoiding depressing the relative humidity, or of controlling excessive relative humidity (given that the dew point would remain unchanged between the measured conditions and the "what if" conditions).



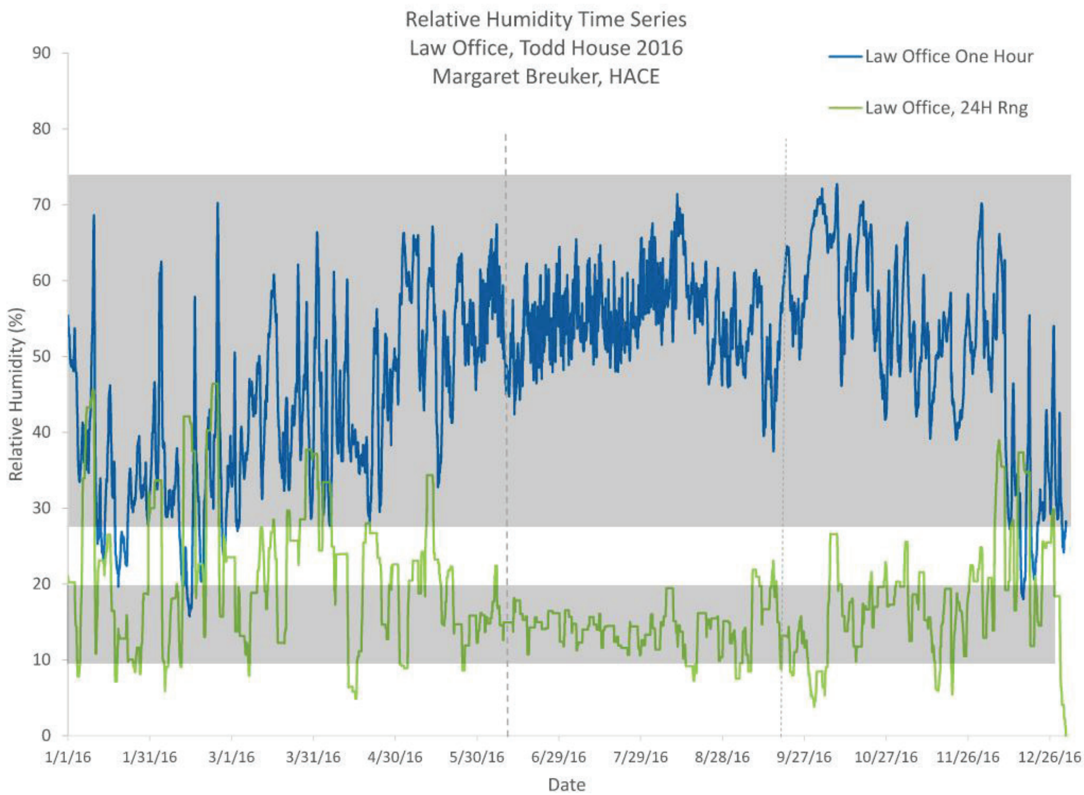


FIGURE 14 (top). **Relative humidity data plotted on cumulative relative frequency chart.** **FIGURE 15 (bottom).** **Relative humidity data plotted as time series, showing running averages for durations of interest** MARGARET BREUKER, HACE

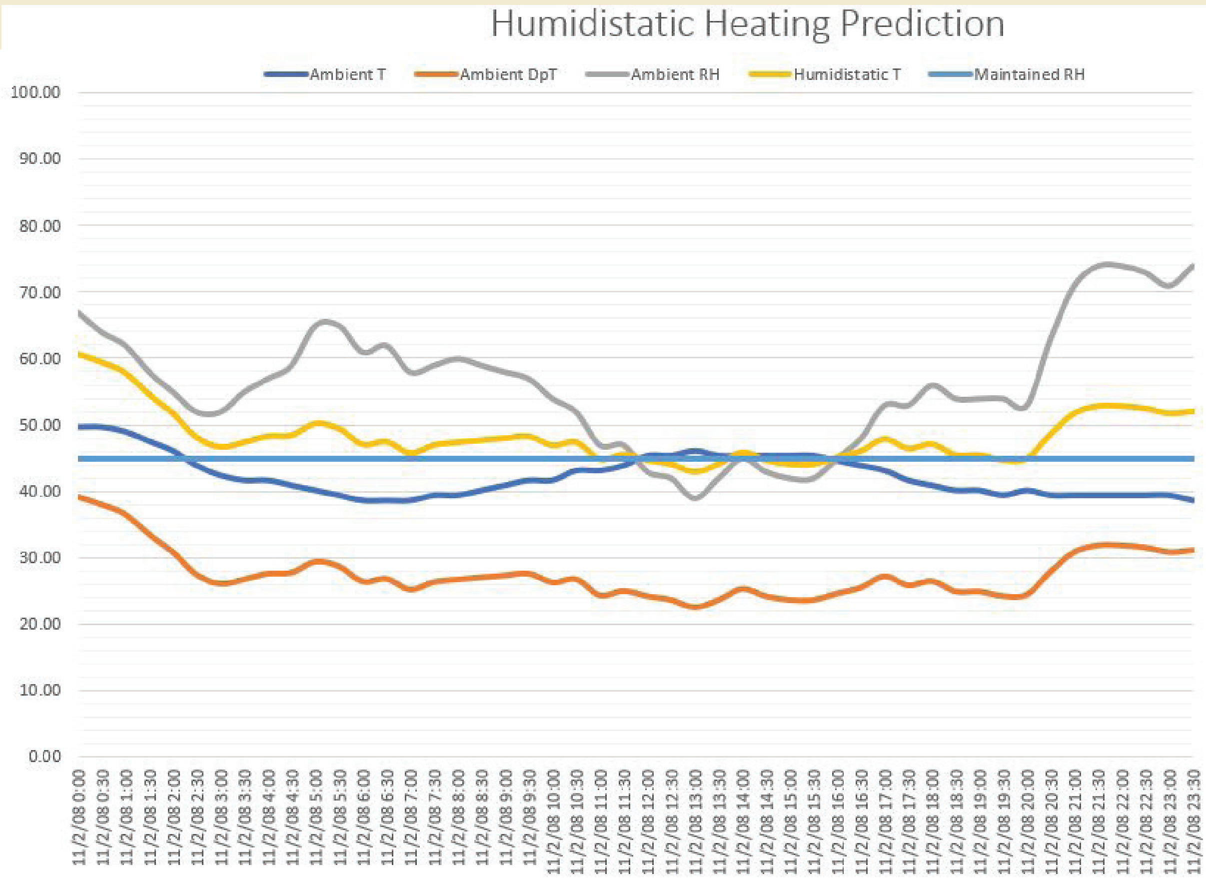


FIGURE 16. Predictive ("What if") plot showing the effect of manipulating temperature to hold relative humidity constant, given previously measured conditions. MARGARET BREUKER, HACE

RECOMMENDATIONS

Respect the historic structure for what it is. It is not a purpose-built climate-controlled museum, and the objects by and large have likely acclimated to the conditions they have spent their lives in. Where acclimatization has been problematic, consider installing reproductions in their stead, or displaying the objects in more benign microclimates (such as climate-controlled museum cases).

Use the original design features of the historic structure to best advantage, where possible.[11] Open and close windows at appropriate times. Maximize informed use of historic ventilating features (towers, light and air shafts, central hallways, roof hatches, skylights, etc.) (Figures 17, 18).

Consider "outside the box" conservation approaches to interior climate mitigation, such as humidistatically controlled heating, strategic deployment of fans, dew point-controlled ventilation, or evaporative cooling (where climate zones permit). Often, these strategies will produce interior environments that are not up to modern comfort standards for docents or visitors; or for staff that spend long hours in the structure. In such cases, employ "refuge stations" (either heated or cooled) in places that can be isolated, and otherwise separate staff functions in spaces that can be locally mitigated with portable equipment.

Consider localized mitigation rather than new centralized systems. Install portable units in critical locations and install discrete infrastructure that supports their daily servicing.

With respect to permanently installed equipment, avoid compromising viewsheds and soundscapes. Unimpaired integrity of both these are critical to the visitor experience, and sometimes to community relations as well. Modern mechanical equipment in historic settings should be neither seen nor heard.

FIGURE 17 (left). Lindenwald—ventilating tower. DAVID BITTERMANN **FIGURE 18 (right).** Lindenwald—tower stair. MARGARET BREUKER, HACE

CONCLUSION

It has been pointed out that one reason expectations for tight environmental control in museum settings is that we have the theoretical ability to achieve it.[12] There is too often the presumption that a historic structure containing collections can be readily modified without loss of integrity to accommodate extensive mechanical systems supposedly capable of maintaining tightly controlled environments. This sometimes leads to abandoning or outright removal of operable passive features originally designed to moderate interior environments. Worse, historic spaces and finishes are lost in service of accommodating a myriad of new mechanical infrastructure; and any ability to interpret period mechanical systems is lost as well. Arguments are frequently made that historic sites cannot afford the staffing required to operate passive features (doors and windows, etc.) or to perform the additional housekeeping that may result therefrom. On the other hand, mechanical systems can also place heavy demands on both operation and maintenance, usually more than is routinely budgeted. When these are ignored, negative consequences to structure and collections alike can be severe. Moreover, an over-reliance on energy-consumptive systems as the default solution in lieu of passive approaches carries heavy climate change consequences. Planning for any such upgrades should always take these realities into account.

ENDNOTES

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4. For an overview of the Getty Conservation Institute, refer to: https://www.getty.edu/conservation/about/index.html.
5. ASHRAE [American Society of Heating, Refrigerating and Air-Conditioning Engineers]. 2015, "A23—Museums, Galleries, Archives, and Libraries." Chap. 23 in *ASHRAE Handbook—HVAC Applications*, Inch-pound ed., 23.1-23.2. Atlanta, GA: ASHRAE (Table 4, p. 23.14).
6. Annelies Cosaert, Vincent Laudato Beltran, Geert Bauwens, Melissa King, Rebecca Napolitano, Bhavesh Shah, and Joelle Wickens. 2022. *Tools for the Analysis of Collection Environments: Lessons Learned and Future Development*. Research Report. Annelies Cosaert and Vincent Laudato Beltran, eds. Los Angeles: Getty Conservation Institute (pp. 17–18 and Appendix 3). https://hdl.handle.net/10020/gci_pubs_analysis_collection_environments.
7. Cosaert et al., pp. 14–16 and Appendix 3.
8. Cosaert et al., pp. 14–16 and Appendix 3.
9. Cosaert et al., pp. 12–13.
10. Douglas W. Nishimura. 2011. *Understanding Preservation Metrics*. Rochester, NY: Image Permanence Institute, Rochester Institute of Technology. See also: Patricia Ford, Peter Herzog, Jeremy Linden, James Reilly, and Kristin Smith. 2012. *IPI's Guide to Sustainable Preservation Practices for Managing Storage Environments*. Rochester, NY: Image Permanence Institute, Rochester Institute of Technology (pp. 54–58). https://www.imagepermanenceinstitute.org/research/environmental.html.
11. Bear in mind that not all historic design features may be worthy of preserving without alteration. This may especially apply to some historic mechanical systems, which although of high interest, may be extremely inefficient in operation. Historic passive systems are quite another matter, however.
12. A premise discussed by Michael C. Henry in his presentation "The Heritage Building Envelope as a Passive and Active Climate Moderator: Opportunities and Issues in Reducing Dependency on Air-Conditioning." Contribution to the Experts' Roundtable on Sustainable Climate Management Strategies, Tenerife, Spain (April 2007).

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