THE ENVIRONMENT

2.2 Monitoring Temperature and Relative Humidity

INTRODUCTION

Collection materials are vulnerable to damage from the surrounding environment whether they are paper, wood, film, leather, parchment, or metal. While we cannot eliminate all of the causes for decay of our cultural records, we can significantly slow deterioration by managing the storage environment. Managing fundamentals of the storage environment such as temperature and relative humidity can be challenging because day-to-day needs and human comfort may take precedence over longer-term climate control activities.

However, monitoring the environment is a foundational element of an overall preservation program. The development of a monitoring program involves gathering information about the institution's building and systems, determining the priority collections that support the institution's mission, and analyzing the needs and vulnerabilities of collections. This process requires the participation of both collections care staff and facilities staff to formulate the best plan for managing the needs of storage spaces within overall management of the institution.

THE ENVIRONMENTAL MONITORING PROGRAM

In order to have an accurate record of existing environmental conditions throughout a building, temperature and RH must be measured *and recorded* with instruments designed for that purpose. The focus of most monitoring programs is on storage spaces, but keeping track of public and staff spaces as well will provide a better overall picture of conditions in the entire building. Concrete, accurate data will document the capability of current climate control systems and provide a basis on which practical temperature and RH goals can be set—particularly in terms of the limitations of existing equipment. Under the best circumstances, monitoring will indicate that available climate control equipment is operating at its ideal capacity. When conditions are not ideal, an environmental monitoring program can be very useful in:

- providing data showing that current climate control equipment is inadequate;
- documenting the severity of existing problems and supporting the need to add or change machinery;
- evaluating the effect of changes that have already been made to existing climate control equipment; and
- guarding against any environmental extremes that might occur during normal operations.

MONITORING THE ENVIRONMENT

Computerized building management systems (BMS) are often used by facilities staff to monitor climate conditions and control HVAC equipment in large buildings or groups of buildings. While these systems can be used to provide temperature and relative humidity data for analysis, there are a few important considerations:

- The system's sensors must be recalibrated periodically to ensure accuracy.
- Sensors must be located properly to ensure that they reflect the climate conditions the collection is experiencing.
- Some sensors should be located in return air ducts to measure air from the controlled space.
- The computerized management system must contain correct locations for the sensors.

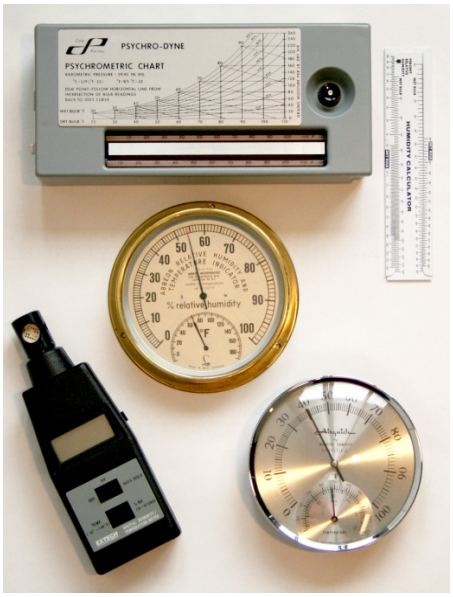
There are various instruments available to measure temperature and RH independently of a BMS. These

instruments fall into two categories: those that provide "snapshot" measurements (i.e., a record of conditions at a specific moment) and those that provide a continuous record of climate conditions. Consider cost, output, precision, durability, and ease of use to determine which type of device is best for your needs.

"Snapshot" Monitoring Devices

"Snapshot" type instruments provide only a rough picture of the environment and are dependent on human participation to read and record data (participation that may not be available after hours or on holidays). Because monitoring by spot readings is labor intensive and human dependent, independent monitoring using continuous recording instruments is recommended.

- **Thermometers** can provide accurate temperature information. A standard thermometer that measures the entire range of foreseeable conditions in a building is satisfactory.
- **Humidity indicator strips or color cards** are an inexpensive humidity-monitoring device. Some are reversible and thus can be reused, while others are for one-time use. Humidity indicator strips provide only approximate readings, but can be useful for indicating extreme conditions.
- **Battery-operated (motor-blower) psychrometer** is a hand-held instrument that measures relative humidity. These are moderately priced and can be moved to monitor a wide variety of spaces. Replacement batteries should always be on hand. It should be noted that they can be complicated to read and require pre-treated water to operate. The non-battery equivalent, the sling psychrometer, is not recommended because of the difficulty in getting accurate readings.
- An **electronic temperature/humidity meter** is another hand-held instrument that uses a calibrated sensor to measure RH at a known temperature. While they are easy to use, many of the models may be accurate only to ±3-5% and may take several minutes to react to humidity changes. These instruments need to be recalibrated periodically (as recommended by the manufacturer).
- **Min/max digital hygrothermographs** keep a record of the highest and lowest temperature and humidity since the instrument was last reset manually; this can be done at any desired time interval (e.g., once a day, every morning and evening, once a week). Humidity measurements tend to be accurate only to about ±5% at mid-range temperatures (accuracy may be less at temperature extremes), but these instruments can provide a broad outline of climate conditions.



Snapshot monitoring devices including a psychrometer, a digital humidity/temperature meter, and thermometers with humidity indicators.

Continuous Monitoring Devices

Data loggers are the most commonly used continuous recording devices in cultural heritage institutions. Recording hygrothermographs were the standard for many years, but they have been replaced with digital data loggers. Data loggers are easy to use and allow the user to create graphs that allow for more robust data analysis.

Data loggers are battery-powered instruments that use electronic sensors and a computer chip to record temperature and RH at intervals determined by the user. Data is downloaded to a computer, and the associated data logger software allows the user to produce customized charts and graphs that illustrate conditions over time. Data loggers can be moved

easily to monitor different locations with a single monitor, provided the data logger's memory is erased before the logger is moved to a new location.

Purchasing data loggers is an investment. Consider some of the following questions when deciding on what type of data logger to purchase:

- **What is the building structure like?** Some data loggers use Bluetooth or your wireless network to send data to a main computer, a function which may not be possible in all buildings.
- **What type of building management system is used?** The information recorded by some data loggers can easily be incorporated into a building management system (BMS), so that the data can be meshed with data collected from the BMS as well.
- **What is the software like?** Some data loggers come with software that can do most of the analysis for you. Others provide only simple graphs.
- **How is the space used?** Some data loggers are small and unobtrusive; others are quite large. Depending on where you plan on placing your loggers, you might consider how they will be seen—or if you want them to be seen.
- **What is the required frequency of measurements and downloads?** Data loggers have different memory capacities and, depending on how frequently measurements are taken, will require downloads.
- **How accurate do the readings need to be?** Some loggers use sensors that are temperature-compensated—meaning the logger can provide about 3% accuracy for RH over a wide range of temperature and humidity—while others do not. Also, some sensors may have a "time-lag" of 4 or 5 minutes if the humidity is falling. This would be a disadvantage if frequent sampling is required.

Recording hygrothermographs are still in use in many institutions. Regular maintenance is essential since they are expensive to replace. Hygrothermographs also require periodic calibration, preferably quarterly. For information on calibration, see the National Park Service's Conserve-O-Gram 3.2, *Calibration of Hygrometers and Hygrothermographs* at https://www.nps.gov/museum/publications/conserveogram/03-02.pdf **Error! Hyperlink reference not valid.**. For all other maintenance, follow the manufacturer's recommendations in the manual.

Recording hygrothermograph

Deciding What Equipment to Buy

Cost, complexity, and time will inform your purchase decision. Look at options from a number of suppliers and compare the features and prices of their equipment. If the supplier does not provide all the information you need, ask questions. The National Park Service and the Conservation Center for Art & Historic Artifacts have both done comparisons on different types of loggers (http://www.nps.gov/museum/publications/conserveogram/03-03.pdf and https://ccaha.org/sites/default/files/attachments/2019-11/2019%20Environmental%20Datalogger%20Quick%20Comparison%20Chart.pdf).Talk to colleagues who have developed environmental-monitoring programs for their input on how well their devices are working. Finally, some organizations (e.g. state library programs) offer monitoring equipment on loan, and you can try out whatever equipment is available and/or use the loan program in lieu of purchasing your own equipment.

The following questions are important to ask in making an informed decision:

1. **How will you use the data?** Are you recording the effect of the operating changes of your

climate-control equipment or do you want to document when conditions in your collection fall outside acceptable limits?

2. **What are the extremes of temperature and RH** that the instrument needs to measure? Will your instrument record the entire predictable range?
3. **How precise do your measurements need to be?**
4. **Do you need to record information when the building is unoccupied?**
5. **What resources are available for calibration, operation, and maintenance?** Who will be responsible for these tasks, and what skills do they have? Can you afford both a recording instrument and a calibration instrument?
6. **How many spaces to you need to monitor** and for how long? How many units will you need?
7. **Is the accompanying software (if any) easy to use**, and does it provide the data and analysis you need? The Image Permanence Institute's online software program, eClimateNotebook (https://www.eclimatenotebook.com/), is an example of software that is compatible with a number of different dataloggers.

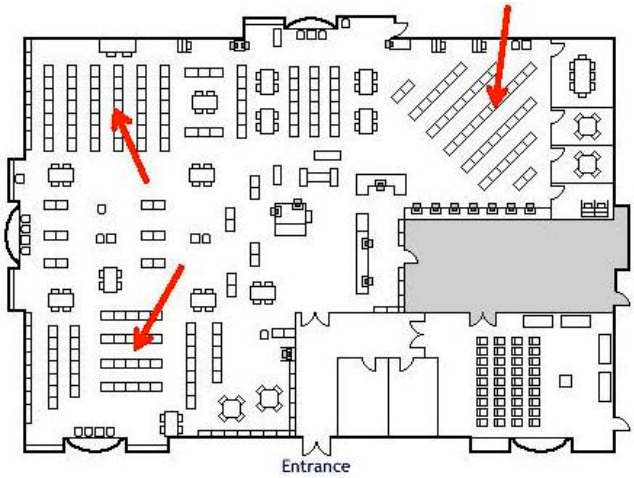
THE MONITORING PROGRAM IN PRACTICE

A good environmental monitoring program will include a written plan for the placement of recording instruments, how to collect information, when to collect information, how to present information, and how to maintain instruments. Monitoring should be the assigned responsibility of a specific person within the institution (with a designated back-up person to cover during absences and vacations). If monitoring depends on a manual—rather than an automatic—recording instrument, the plan should lay out when and how often to take measurements to reflect the widest variation in conditions.

Records of historical weather conditions and special events (exhibit openings, for example) can help to explain variations in monitoring data. For example, a special event where an unusual number of visitors are in a space can alter temperature and RH levels, causing a spike on the data printout. Regional weather records are available from the National Oceanic and Atmospheric Administration's (NOAA), National Climatic Data Center (www.ncdc.noaa.gov), and some monitoring software can link automatically to the closest weather station.

Placement of Monitoring Equipment

The position of monitoring instruments is an important decision. Placement of instruments can impact the accuracy of the measurements or may raise concerns among staff and users as to their purpose. Fundamentally, equipment should be placed above floor level; away from the direct flow of air vents; not on or near heating, cooling, or humidity control equipment; and not adjacent to doors and windows (unless you want to record the impact they have).



Map showing placement options for monitors

For example, in the above library—for general monitoring—place the monitoring device in any of the locations marked by an arrow at about mid-shelf height and positioned to prevent the monitor from being disturbed. The monitor should be away from the entrance since readings near an exterior door can be quite variable.

If a limited number of monitoring instruments are available, or if you have only short-term loan of equipment, a reasonably accurate profile of conditions in several spaces can be developed by leaving an instrument in each area for at least 3 months. The most important information to look at in these snapshots will be the extremes of temperature and humidity and the speed and extent of changes. In all cases, **it is important to collect at least a year's worth of monitoring data in any one location before**

making any substantial changes to building systems or collection locations, since climate conditions in a single space can differ greatly during the different seasons.

Environmental monitoring data serves no purpose unless it is part of an ongoing environmental management process. Whether it is downloaded and analyzed using a computer program or plotted on graphs and analyzed by hand, data will be most useful if recorded on a regular basis. When recording information manually, or if using a recording hygrothermograph, label each chart or form with the location, date, initials of monitor's name, and recalibration information (date, time, how altered). Any data gathered can be kept in a physical or digital folder in an easily accessible location so that stakeholders in the institution can reference it when needed for reporting, maintenance, or budgeting.

EVALUATING CLIMATE AND COLLECTION NEEDS

Regularly gathered data can be used to improve environmental conditions for collections, people, and buildings. When determining equipment settings, there is no right or wrong set point for all collections and, often, institutional energy requirements will necessitate changing or negotiating desired settings. The manager of the monitoring program and the institution's facilities staff can use the accumulated data to determine the actual conditions in each monitored area, assess the effect of those conditions on the collections, evaluate the capabilities of the current climate control system(s), and make changes or redistribute collections accordingly.

Every building and environmental control system will have limitations, and it is important to recognize these limits when making climate-control decisions. Climate control ranges from completely uncontrolled to sophisticated systems that provide accurate control for heating, cooling, and humidification or dehumidification. Knowing what systems exist and what impact existing systems or new systems may have on the building envelope is important. Un-insulated, historic buildings can be damaged simply by the installation of a central heating or humidification system. Such buildings may need major alterations before they can provide an environment that is compatible with the needs of their contents. In these cases, it may be necessary to relocate collections to provide conditions suitable for preservation.

The collections formats in any given institution have different vulnerabilities and require specific storage conditions. For more information on the recommended storage environments for various collection materials, see NEDCC leaflet 2.1, *Temperature, Relative Humidity, Light, and Air Quality: Basic Guidelines for Preservation*, https://www.nedcc.org/free-resources/preservation-leaflets/2.-the-environment/2.1-temperature,-relative-humidity,-light,-and-air-quality-basic-guidelines-for-preservation.

It is also very important to understand the value and relative importance of collections to your institution. Some materials may require stricter climate control by virtue of their relevance to the institution's mission, their research value in their original state, their importance to the collection, or their monetary value.

Facilities staff should be encouraged and welcomed to participate as partners in the monitoring and decision-making processes. Facilities staff are in a position to consider long-term environmental trends in relation to day-to-day needs. They are also knowledgeable about the building and how it and the existing systems work and interact with one another. It is worth noting that HVAC systems are seldom optimally used, even when all the components are in place. A building maintenance engineer or the contractor responsible for the HVAC system can often improve its performance if data is available. Simple actions such as resetting thermostats, replacing filters, or even rearranging furniture to unblock vents can help to improve the environment and cut down on costs.

HOW TO IMPROVE THE ENVIRONMENT

Once collection needs, current climate conditions, and system capabilities have been determined, measures to improve environmental conditions for

museum, library, and archival collections might include:

- removal of collections from attics, which tend to be hot, or basements, which can be damp;
- ensuring windows and doors are well sealed against the outdoors with caulk, window coverings, weatherstripping, etc.;
- creation of storage spaces segregated by type of material (determined by each format's environmental needs);
- improvements in insulation and building seals;
- use of portable air conditioners, humidifiers, and/or dehumidifiers. It is critical to remember that temperature and RH are intimately related and the correction of one factor may alter the balance of other important factors (e.g., a dehumidifier may generate enough heat to require additional cooling); and/or
- installation of central environmental controls.

Common solutions to frequently encountered climate problems include:

- adjusting settings to accommodate for winter and summer conditions (for example, cold and dry or hot and humid);
- moving collections off of walls and into the centers of rooms to combat problems with condensation for institutions that close during the winter months; and
- sealing windows with plastic in the winter and using weatherstripping on doors.

If the existing climate-control equipment was designed to produce the desired conditions, but problems cannot be solved by simple adjustments and routine maintenance, it may be necessary to have the system professionally rebalanced. Balancing is a process that measures airflow and other characteristics of HVAC systems and may require the expertise of a professional HVAC or environmental control engineer. For best results, select an engineer with experience in collections-holding institutions. If no one with this specific experience is available in your region, seek an engineer with experience in climate-control of computer facilities, which can have similar requirements. A design that works well for a hotel or shopping mall will not work for library and archival collections, a historic building, or a museum. Ask for references from clients whose needs may have been similar to your own and talk to those clients about the success or failure of the system designed for them. Make sure your consultant understands what your ideal conditions and minimum requirements will be.

CONCLUSION

As experts study and understand the interaction of all storage factors, managing the environment has come to mean more than simply setting temperature and RH targets and checking for deviation from them. The needs and vulnerabilities of collections must be taken into account, as well as the capabilities and limitations of an institution's building and systems. Accurate environmental monitoring data is one of the most important tools in determining whether existing conditions meet the needs of collections throughout a facility. A properly conducted, systematic monitoring program will enable an institution to accurately assess current success and future needs, as well as to maximize the use of current resources.

RESOURCES

American Institute for Conservation (AIC). "Environmental Guidelines: Museum Climate in a Changing World." Accessed 4 April 2022. https://www.conservation-wiki.com/wiki/Environmental_Guidelines

Conservation Center for Art & Historic Artifacts. "2019 Lower-Cost Environmental Datalogger Quick Comparison Chart," 2019. Accessed 4 April 2022. https://ccaha.org/sites/default/files/attachments/2019-11/2019%20Environmental%20Datalogger%20Quick%20Comparison%20Chart.pdf

"Chapter 24: Museums, Galleries, Archives, and Libraries" in *ASHRAE Handbook: HVAC Applications*, 2019.

Grattan, David, and Stefan Michalski. "Environmental Guidelines for Museums." Ottawa: Canadian Conservation Institute, modified 2017-09-21. Accessed 4 April 2022. https://www.canada.ca/en/conservation-institute/services/preventive-conservation/environmental-guidelines-museums.html

Image Permanence Institute (IPI). Dew Point Calculator. Accessed 4 April 2022. http://www.dpcalc.org/

IPI publications. Dates vary. Downloads at https://www.imagepermanenceinstitute.org/education/publications.html. Accessed 4 April 2022.

Environmental Management and Mechanical System Quick Reference, 2014. https://s3.cad.rit.edu/ipi-assets/publications/hvac_reference.pdf

IPI's Guide to Sustainable Preservation Practices for Managing Storage Environments, 2012. https://s3.cad.rit.edu/ipi-assets/publications/sustainable_preservation_practices/sustainable_preservation_practices_all.pdf

IPI's Methodology for Implementing Sustainable Energy-Saving Strategies for Collections Environments, 2017. https://s3.cad.rit.edu/ipi-assets/publications/methodology_guidebook/methodology_guidebook_all.pdf

The Role of Dew Point in Sustainable Environmental Management, 2016. https://s3.cad.rit.edu/ipi-assets/publications/dew_point.pdf

Understanding Preservation Metrics, 2007. https://s3.cad.rit.edu/ipi-assets/publications/understanding_preservation_metrics.pdf

IPI webinars. Dates vary. Available on YouTube at https://www.youtube.com/c/ImagePermanenceInstitute. Accessed 4 April 2022.

"Energy Monitoring for Cultural Heritage Institutions," 2021. https://youtu.be/gO7Xaygwb2c

"Evaluating Collection Spaces," 2019. https://youtu.be/eS-lsbdjLXc

"Introduction to HVAC Systems," 2021. https://youtu.be/v4yWRQC57wg

"Responding to Issues," 2020. https://youtu.be/XpLoNe3GrxE

"Setting Appropriate Parameters," 2020. https://youtu.be/An2lq7sYnWk

"Understanding Fluctuations and Equilibrations," 2020. https://youtu.be/AkCpK1ORWrw

International Council of Museums – Committee for Conservation. "Environmental Guidelines ICOM-CC and IIC Declaration," 2014. Accessed 4 April 2022. https://www.icom-cc.org/en/environmental-guidelines-icom-cc-and-iic-declaration

National Park Service. *Conserv-O-Gram 3-2: Calibration of Hygrometers and Hygrothermographs,* 1993. Accessed 4 April 2022. http://www.nps.gov/museum/publications/conserveogram/03-02.pdf

National Park Service. *Conserv-o-Gram 3-3: Comparing Temperature and Relative Humidity Dataloggers for Museum Monitoring,* 2011. Accessed 4 April 2022. http://www.nps.gov/museum/publications/conserveogram/03-03.pdf

NEDCC. *Preservation Leaflet 2-1: Temperature, Relative Humidity, Light, and Air Quality: Basic Guidelines for Preservation*, 1999. Accessed 4 April 2022. https://www.nedcc.org/free-resources/preservation-leaflets/2.-the-environment/2.1-temperature,-relative-humidity,-light,-and-air-quality-basic-guidelines-for-preservation

Pacifico, Michele F. and Thomas P. Wilstead. *Archival and Special Collections Facilities: Guidelines for Archivists, Librarians, Architects, and Engineers*. Chicago: Society of American Archivists, 2009. https://mysaa.archivists.org/productdetails?id=a1B0b00000el1A5EAI

Wilstead, Thomas P. *Planning New and Remodeled Archival Facilities.* Chicago: Society of American Archivists, 2007. https://mysaa.archivists.org/productdetails?id=a1B0b00000gJe1iEAC

ACKNOWLEDGEMENTS

Written by NEDCC staff. Updated by Ann Marie Willer, 2022.