METHODOLOGY:
GATHERING ENVIRONMENTAL DATA

Accurate, reliable data is essential to sustainable and optimal environmental management. You will need access to temperature, relative humidity, and dew point readings from spaces containing collections, as well as outdoor data from your location. A comparison of outdoor air data with indoor data is needed to accurately assess HVAC system operation, since temperature and relative humidity relate directly to HVAC operation and energy use, and are the primary drivers of material decay.

Gathering Collections Space Data

Monitor continuously. Effective data analysis requires a full year of data, including seasonal extremes (summer heat and humidity, winter dryness) and both heating and cooling seasons. Data collected over a short period of time has limited value for long-term preservation and operational analysis.

Collect and review data routinely. Depending on your situation, this could be quarterly, monthly, or even weekly during periods of high temperature, or high or low humidity.

The optimal number and location of dataloggers needed depends on a number of factors. Consider placement within all rooms housing collection materials, and especially:

- Locations housing important and/or vulnerable collections;
- spaces that have had environmental problems in the past; and
- areas with potential vertical stratification or microclimates.

To analyze the functions and capabilities of mechanical systems, you will need dataloggers in different spaces served by the same system, as well as locations served by multiple mechanical systems. In a large space, you may need to place additional dataloggers where you have reason to believe conditions differ significantly.

Place dataloggers near collections. On shelves or racks placement four to six feet from the floor is recommended. For high bay or multi-level stacks placement at various levels is helpful. When placing dataloggers inside a display case, avoid placement too close to light sources. Always place dataloggers away from supply ducts, exterior doors and windows, or heat sources, when trying to get an average reading for the space; if you want to measure their effects though, dataloggers in these locations may be useful. (Additional information is provided in *Datalogger Placement in Collections Spaces* later in this section.)

Effective environmental management requires the use of electronic dataloggers and a computer software program that produces data graphs and tables. Standalone, battery-powered electronic dataloggers are the most popular and practical choice. Consider the datalogger's accuracy, operating range, battery life, memory capacity, and ease of upload.

IPI developed the Preservation Environment Monitor (PEM) and the PEM2® specifically for use in cultural institutions. The PEM2® datalogger has highly accurate temperature and RH sensors, 5-point NIST Traceable Calibration, and USB flash drive upload.

Networked datalogger systems provide real-time data using wireless or hard-wired technology. Although these systems don't require frequent, physical data collection, they can be impractical to install, difficult to configure, and data reception can vary.

In some cases, data from Building Management Systems (BMS) can be used. Modern BMS software can often store and export data and some systems provide trending data. However, BMS sensors are not always ideally located. BMS system designs are proprietary, with security and access restrictions, and data export can be difficult and time-consuming.

Another option for gathering environmental data for storage and analysis using IPI's eClimateNotebook® web software has recently become available. Rather than relying exclusively on standalone electronic dataloggers, this new approach brings environmental data from building management systems (BMS) directly into eClimateNotebook®. Sensors in spaces, ducts and outdoor locations that are connected to the computers that run building HVAC systems can now feed environmental data directly, and in real time. This is accomplished through the use of secure network communications that can access web services provided by the BMS. IPI has had several successful implementations of this with proprietary BMS systems such as Tridium Niagara® and Siemens Insight®. In some instances information is harvested directly from the BMS, while in other cases data is transmitted via "file dumps" using email.

Gathering Mechanical Systems Data

Data from a space tells a critical part of the story – what the collections experience – but it does not provide much information on how the environment was created. To gain that information, data should also be gathered from inside the mechanical systems themselves. (Additional information is provided in *Monitoring Inside an Air Handling Unit* later in this section.)

IMPORTANT!
Review the Safety Precautions section in the Introduction of this guide before initiating mechanical systems data.

As with environmental data, there are two primary options for gathering mechanical data - stand-alone digital dataloggers and data from a BMS system. Which choice is better depends on a variety of factors – whether the BMS data is accessible and can be exported, the relative accuracy of the sensors (when was the last time the BMS sensors were calibrated?) and the location of the sensors everywhere they are needed. Sometimes a combination of dataloggers and BMS data can be used if there are one or two data points missing from the BMS system.

Monitor continuously. As with collections space data, effective data analysis requires a full year of data, including seasonal extremes (summer heat and humidity, winter dryness) and both heating and cooling seasons. Different seasons and energy loads will cause the mechanical system to alter operation; the goal of data logging is to track those alterations and see what type of operation is being performed, and how much energy it uses. Because mechanical operation can change over the course of even a day, sampling rates for data points should be set at least at every 30 minutes or less.

Collect and review data routinely. Best practice for mechanical data logging is to gather data at least monthly. Due to the conditions within the mechanical units (condensation, high heat, pollutants), datalogger failure rates may be greater than those experienced in the collection space. Monthly data gathering allows for a minimum of data loss if there is an issue.

The number and location of dataloggers or sensor points will vary with each mechanical system, but the goal should be to gather data from each point where the condition of the air may change (heated, cooled, humidified, or dehumidified).

Consider placement in:

- Return air;
- Outside air;
- Mixed air (typically after filters);
- Cooled air;
- Heated air;
- Humidified air;
- Supply air – this may be the same as the heated or humidified air, or it may be further downstream after a VAV box or downstream reheat

Placement within the air stream is critical; if using dataloggers, strive to locate them in the center of the air stream to get the best representative blend of conditions.

Options for Data Collection Instrumentation

Monitoring the environment is not a new concept. Hygrothermographs were used by scientists in the 1860's to take measurements in their labs. These machines have lived on in a similar form and are still used by some institutions. The advent of the digital world has brought smaller, more accurate and better machines that are capable of storing months or even years worth of data. With the plethora of options to choose from, it is important to know the value and drawbacks of each of these types of dataloggers.

Hygrothermographs

These are one of the oldest tools used for environmental monitoring. These devices are chart recorders that measure temperature and relative humidity. The recordings are made by pens on the end of metal rods that leave marks on a rotating piece of paper. The rotating paper must be changed routinely (based on chart time span – weekly or monthly, etc.) to avoid overlapping the data. The recorded data must then be physically stored somewhere in order to keep a record of the environmental conditions. This can, in some cases, result in hundreds or thousands of charts from these dataloggers taking up shelf space in institutions. Analysis of this data can be very complicated; while tools have been developed to scan and digitize the data trends, typically analysis requires a review of data over dozens of sheets. This can make tracking dew point and evaluating long-term environmental risks extremely difficult.

The size of a hygrothermograph is also a factor in its appropriate usage. These recorders can be bulky and typically require a large footprint with adequate air space to function properly. This bulkiness makes them hard or impossible to use inside of display cases or small areas. Hygrothermographs also require constant care – pens and papers must be maintained, regular recalibration is necessary, and newer versions of the recorders require a power source to ensure they can record. These issues combined with the high price (a new unit can cost $1000-$1200) can make hygrothermographs a poor choice for many institutions.

Drawbacks

- The average price of one new hygrothermograph is almost equal to the price of three mid-level dataloggers

- They are normally large pieces of equipment
- Must be wound, battery powered or plugged in
- The relative humidity arm may be calibrated by a human hair, requiring regular recalibration and media replacement
- Best-case accuracy is typically less than stand-alone dataloggers
- Storage of charts requires physical space
- Charts can be hard to analyze for trends, dew point or issues
- Forgetting to change the paper or replace a pen may ruin a period of data

Electronic Dataloggers

The data collection method you choose will impact the most important part of the monitoring process—interpreting the data and using it to make improvements to the storage environment. When considering electronic dataloggers, a common mistake is focusing solely on the price of the datalogger and not comparing accuracy, reliability, and ease of use.

Electronic dataloggers range in size, shape, design, and in recording capabilities. Some are slightly bigger than a deck of playing cards while others are round and the size of a large coin, allowing these dataloggers to be used for monitoring methods that hygrothermographs never could accommodate. Electronic dataloggers are the modern solution to accurately, quickly, and easily recorded data. Most dataloggers are capable of recording temperature and relative humidity, but others have functions for logging light levels or more specific mechanical data. They typically require less maintenance than hygrothermographs, and can easily store months or even years worth of data, meaning that some can go months without requiring a data pull. When the data is retrieved, the information can be easily accessed on a computer and analyzed.

Almost all electronic dataloggers have their own proprietary software that can graph the temperature and relative humidity. Keep in mind that most of these products are made for a wide group of cross-disciplinary users, including laboratories, manufacturing, building management, and food and pharmaceutical storage. Be certain that any software that is chosen is capable of exporting the data files to a text or comma-separated value file, so that data remains accessible if the institution changes software or datalogger brands. For cultural heritage institutions, access to calculated dew point graphs is also critical.

Data from electronic dataloggers can be easily stored and organized. Once the data is pulled from the dataloggers it can be loaded into a computer and saved onto a hard drive or flash drive. This makes the relatively small size of these files (normally less than 100kb each), easy to store and organize, especially as digital storage gets cheaper and cheaper.

Electronic dataloggers can now be placed inside of display cases, used to monitor conditions inside of drawers, used to track the changing air conditions through an air handling system, or even used to monitor electrical voltage from air handling unit fans. Be aware of what your data needs are, and choose the style and data collection capability that best suits the situation.

Stand-alone Dataloggers

These dataloggers are among the most popular types of dataloggers, and are practical for a number of applications. The price of these dataloggers varies, and can range from $100 to $1000. Typically battery-powered, most have internal memory for data storage, allowing them to record continuously for extended periods of time. Data-transfer to a computer is different from brand to brand; some use USB drives while others may use a specialized cable connection to a laptop or other data transfer device. Once the data is on a computer it can typically be viewed as a graph and analyzed using proprietary software.

Stand-alone dataloggers offer a variety of options that may enhance the logging capabilities. As a general rule, the more features a datalogger has the greater the potential impact on the battery life of the unit.

Display

- Some dataloggers have displays built into them. These displays may show battery power, temperature, RH, or time, among other values.

Remote probes

- Some dataloggers have ports built into them that allow for the addition of probes to monitor a variety of conditions such as temperature, RH, electrical current, voltage, CO_2, air velocity, or volatile organic compounds (VOCs).

Alarms

- Some dataloggers have audible alarms that may sound if the battery is low, there is a dangerous environmental condition, if the memory is getting full, or for other factors.

Lights

- Similar to audible alarms, some dataloggers come equipped with warning lights on them. These lights are designed to flash if the battery is low, there is a dangerous condition, if the memory is getting full, or for other factors.

Radio Frequency and Hard-wired Dataloggers

These dataloggers are very similar to stand-alone dataloggers except they can transmit the data directly from the datalogger to a computer, cell phone, or tablet. Rather than human retrieval via computer, flash drive, or other method, the data is automatically uploaded and ready to view via the associated software. These dataloggers have proven to be very useful in display cases or vitrines where the case needs to stay sealed but the data from the internal environment is still needed. They can also be useful in monitoring areas that can be hard to reach due to height or other factors.

These dataloggers utilize different methods to transmit data to a computer. Though the benefits of these dataloggers are similar, each of these technologies can have their own drawbacks.

RADIO FREQUENCY

These dataloggers use a radio frequency – typically Wi-Fi or Bluetooth to transmit a signal to similar dataloggers or to a receiver. This signal is then sent from the receiver to the computer. The receivers are purchased at an extra cost. Loggers may also connect to a phone app, tablet, or other wireless or Bluetooth device.

Benefits

- Can be useful for monitoring hard to reach locations
- Can be useful in cases or vitrines where the collection should not be disturbed

Drawbacks

- May require multiple receivers
- Stone and steel structures may make it hard to transmit a signal
- Initial set up may be time consuming
- Signal reception can be difficult at times, and may require line-of-sight
- Though a device may receive Bluetooth it is not a guarantee that the dataloggers will connect to it

ETHERNET-CONNECTED

These dataloggers need to be hard-wired to an Ethernet port to ensure that data can be sent.

Benefits

- Can be useful for monitoring hard to reach locations
- Can be useful in cases or vitrines where the collection should not be disturbed

Drawbacks

- Requires an Ethernet port
- In some cases, unknowing staff have unplugged dataloggers
- In the event of a power loss the datalogger would not record

Electrical Monitoring Dataloggers

Normally, a datalogger that records electrical data is not a necessity for a cultural institution; however, they play a significant role when attempting to monitor shutdowns or fan speed adjustments. These dataloggers monitor the main electrical amperage ("amp" logging) to a fan; when the fan is shut down or slowed down this data is recorded by the datalogger. This is an excellent way to evaluate if system shutdowns or fan speed slowdowns are occurring.

Electrical dataloggers can either be purchased as separate stand-alone electrical monitoring dataloggers or may be a standard datalogger that has a communication port for a current transducer (CT) that can monitor one of the electrical power legs to a fan. This datalogger should only be installed by a qualified electrician or a facilities professional who is permitted to work inside of an open electrical or VFD/VSD box.

Water-Resistant Loggers

Most dataloggers are not meant to be used in harsh or damp conditions. When exposed to condensing conditions, many dataloggers will fail due to electrical shorts. Data logging within an HVAC system may require the use of water-resistant dataloggers near the cooling coil or near the humidifier – high-moisture locations that create the potential for a standard datalogger to fail. Specialized dataloggers are available that are designed to withstand condensing conditions, typically through conformal coating of the circuit board and a sealed outer case with no display.

General Logging Guidelines

- Your goal is to improve the preservation quality of the environment for your collection. You cannot manage what you do not measure.
- Hygrothermographs are generally not recommended to use as monitoring devices.
- When purchasing dataloggers make sure the battery life is sufficient to record at least one year's worth of data.
- Keep dataloggers in one place and do not move them. The more data available from a location, the better the analysis that can be performed.
- Accuracy of dataloggers is important. Be sure dataloggers are calibrated according to manufacturer's recommendations to be as accurate as possible.
- Be sure to perform a data pull from the dataloggers at least once a month.
- Be sure to keep back up files of all of your datalogger data.
- Recording outside data will allow you to compare exterior conditions to interior conditions and help evaluate the work the system is performing.
- The information you are gathering will build a history of the environmental conditions to which the collection is exposed.
- Secure any dataloggers in public locations to ensure they do not go missing.
- If it is possible to program the sampling rate of the datalogger, it is recommended to set the sample rate for a maximum span of every 30 minutes.
- Do not rely solely on the sensors from the Building Management System. These sensors can often be out of calibration, and, in the case of space sensors, may not be near the collection.

Datalogger Placement in Collection Spaces

Data logging is not always a simple one-to-one relationship where you purchase and deploy one datalogger for each room you have. Calculating the number of dataloggers you need and where to place them involves establishing a plan for your data-monitoring. The objective of data logging is more than simple data collection – it is collecting data from the appropriate locations to be able to better analyze and improve the storage environment for preservation. As such, there is no "magic" number when it comes to how many dataloggers are needed – it may be as simple as one per room, it may be several in large collections storage areas, or it may be one primary one for a space, and several others that are monitoring microclimates or past problem areas. The key is to identify what information you need, to establish a plan for how best to collect it, and gather it regularly to facilitate analysis.

When monitoring a **collection storage space** overall there are a few guidelines to follow:

- Try to keep the dataloggers where the collection lives.
- Keep dataloggers 4-6 feet off of the ground. In many rooms, this should be about the middle height of the room, where most of the collection materials are and away from the warmest air at the ceiling and the coolest at the floor.
- Loggers can be placed in drawers or cabinets to monitor these microenvironments.
- Do not pack dataloggers tightly in between materials – accurate readings require airflow.
- On shelving try to keep a few inches around dataloggers free for air movement.
- Keep dataloggers at least 3 feet from a supply air vent.
- Unless logging for this specific purpose, keep dataloggers away from false sources of heat such as windows, heaters, or lights.
- Unless logging for this specific purpose, keep dataloggers away from sources of moisture such as active leaks or sinks.
- If there is reason to believe conditions may differ within a space, use a datalogger to confirm the presence and severity of a microclimate.

The guidelines for monitoring in an **exhibition space** are quite similar, with a few exceptions.

- Consider using wireless dataloggers especially when deploying equipment in difficult to access spaces.
- Most dataloggers have loops or mounting holes on them for use with screws or nails. These can be used to mount a datalogger to a wall or other surface to prevent it from being tampered with.

Other factors to consider depend on your goals for data collection and analysis. For example:

- In a historic house, consider monitoring north and south facing rooms which receive differing amounts of heat from the sun. This is to document heat loads that influence the temperature in the space. Document the environment at different levels in the building—hot attic spaces, damp spaces next to exterior walls, or locations near radiators or other sources of heat.
- Identify potential moisture problems by monitoring basement storage locations in historic buildings. High humidity levels may result from water leaks, wet walls, foundations with poor drainage, or high levels of ground water.
- You may want to monitor the environment in areas that hold the most significant or the most vulnerable materials in the collection.
- Lending institutions may want to see environmental conditions of gallery spaces before approving a loan.
- Monitor collections spaces that are served by different HVAC systems; environments may differ due to the function and capabilities of each individual system, and opportunities for improvement may vary. For example, data may show the need for additional humidification or dehumidification during certain times of the year.
- In areas where the HVAC system does not seem to be working properly, environmental data can help

document the system's ability to hold a set point, or can illustrate temperature or RH fluctuations.

- You may want to document or confirm potential stratification in a space with high ceilings or many open levels (such as library stacks or high bay storage).
- Monitor locations that have had environmental problems in the past to justify the need for improvements or to document the result of improvements that have been made.
- If environmental conditions vary from what is expected, consider monitoring adjacent rooms to determine whether they may influence the space.

Whatever the logging plan, it is important to leave a datalogger in the selected location for a full year so that the data covers any change of seasons and mechanical operation.

If you have a number of dataloggers throughout your facility, you should document their location for future reference. Marking the dataloggers' locations on a floor plan or chart detailing their information (serial number, identifying name) and location particulars (shelf number, location description) is critical – in the event of staff turnover or changes in responsibility, other staff or colleagues working with the data will be able to locate and continue gathering data. Images of dataloggers and their locations can be useful as well.

Be sure to collect data routinely; in most cases, once a month is sufficient, although you should gather data more often during testing or experimentation phases. Routine data pulls and analysis can help expose problems before major damage occurs. Ideally, data should be gathered and analyzed after any major event or storm to determine that environmental conditions and system are operating as they should.

Monitoring Inside an Air Handling Unit

Understanding how the air-handling unit functions and what work is done to the air stream at each step is critical to understanding how the preservation environment is created. Visiting the unit and determining the layout is an important initial step; adding operational data from the individual coils, the humidifier, and other components helps quantify how much work is actually being performed. Data logging within an air handling unit provides the information that becomes the basis for energy and operational analysis, appropriate experimentation, and assessment of any tests conducted.

Monitoring and collecting data within an air handling unit can be challenging. It is essential to work with your facilities management staff to understand the functions and capabilities of your mechanical system and to identify any possibilities for improving the environment for long term collection preservation. Facilities staff should take the lead in mechanical data logging – not only is the equipment their responsibility, but they typically have far greater experience working around the air-handlers. Data logging safely is critical not only for protecting staff but for protecting the equipment as well.

IMPORTANT!
Review the Safety Precautions section in the Introduction of this guide before initiating mechanical systems data.

You should verify with your facilities representative if your institute has any special protocols or procedures, other than the ones we provide when working with the HVAC equipment. Many institutions have very strict policies regarding access and work in or around the equipment. These policies exist to prevent accidents that can harm an individual or that can damage equipment. **Be sure to follow and adhere to all safety precautions**.

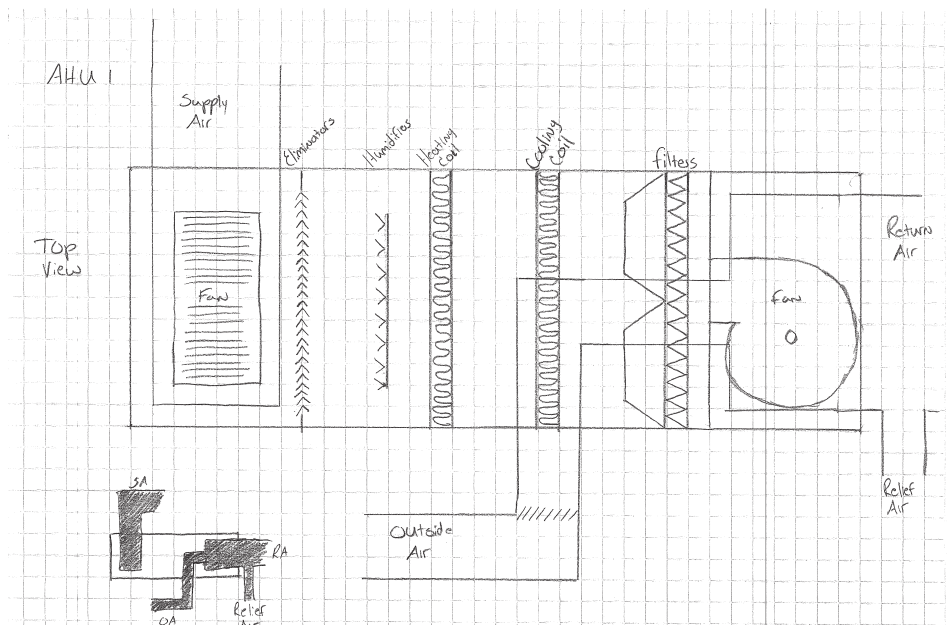
The following outlines the steps for setting up a monitoring program within an air-handling system. No two systems are exactly the same; each unit will require some thought regarding appropriate installation of dataloggers.

Step One: Visit the unit and visualize the layout

Work with facilities or HVAC team representatives to visit the mechanical room and the air-handling units in question. Bring a pen and paper with you, and while at the unit make a quick sketch of its layout. The sketch does not need to be of artistic quality – the goal is to provide a basic understanding of the system layout.

There are some parts or functions of the unit that should be identified. Below is a list of components that you should be looking for when sketching your unit – work with facilities colleagues to identify which components the system may have and where they are located. Not all units will have every component/function listed below.

Function



- Air flow direction
- Mixed air (combination of return and outside air)
- Return air
- Supply air
- Outside air

Component

- Supply fan
- Return fan
- Preheating coil
- Cooling coil

- Heating coil
- Humidifier
- VFD/VSD

Step Two: Analyze the sketches for datalogger placement

After the sketches of the unit are made sit down with facilities or HVAC representatives and identify proper locations to install dataloggers. These locations should be safe to access, and ideally in locations that will not damage the dataloggers. The goal is to collect data after each section of the HVAC system, which will allow the team to analyze the data and identify the work that each section is performing. Once the operation and energy usage are documented, the team can make an informed decision towards changing the operation.

Step Three: Place dataloggers

Again, facilities staff should take the lead on this task, and work to introduce other team members to the inner workings of the HVAC systems. The available work space inside an individual AHU can be very tight; placing dataloggers should be done with the utmost care. Keep the following in mind while selecting datalogger locations and installing them:

- Always follow your facility's safety procedures, and use caution when working around the AHU.
- Follow the buddy system (always have two people present), and always have a facility or HVAC representative on hand.
- Ideally, make sure the AHU is turned off before entering the unit.
- Do not wear any dangling or loose items (ties, scarves, lanyards, necklaces, etc.); these items can be pulled into a fan if the unit is running.
- Do not touch or alter anything in the unit without approval. If an issue is noted report that issue to facilities rather than attempting to resolve it.
- Do not take any actions or touch any equipment you are uncomfortable around.
- Be sure to carry a flashlight and cell phone when working around HVAC systems.
- Watch your hands and feet at all times – sharp metal edges are common, and drain lines and piping may run across the floor.
- Know where the emergency shut-off for the unit is.
- Most dataloggers have loops on them. Use these loops to attach a zip or cable tie to mount the dataloggers.
- Never hang a datalogger off of a fan or a mount for a fan – the vibrations can damage dataloggers.
- Try not to place dataloggers on the face of a cooling or heating coil.
- When trying to get a mixed air condition, get as far into the unit as possible before any work is done to

the air. Normally this is after the filters. This allows for the most reliable mix of the outside and return air.

- If possible, use extension cables off of the dataloggers to allow for data pulls without entering the unit.
- If using extension cables, ensure that the cords are not cut or crimped as they exit the unit, and that the doors on the unit all shut properly.
- If no other means are available, heavy duty Velcro or plastic adhesive loops with a zip tie can be used to attach a datalogger to the side of an air handling unit.

Step Four: Pull data

Data pulls from dataloggers should be performed at least once a month. Depending on the installed location of the dataloggers, the layout of the air handling system, and your facilities guidelines you may need permission and a facility person to accompany you before going back to the unit to pull data.

If any datalogger is found to be defective, it should be replaced immediately. Upload of the data and an initial check for completeness should be performed the same day as the data pull – this allows an additional check to make sure that all dataloggers are functioning properly.

A full review of the downloaded data should be performed within a week of the data pull, and should include all members of the team. The data should be analyzed for trends or issues as well as for the unit's normal daily or seasonal operation.

Other Tools

When performing your own facility and sustainable preservation analysis, it is important to have the right tools on hand. Though dataloggers are currently the best method for long-term monitoring of a collection space or mechanical system, there are a number of other tools that can prove useful for spot-checks or initial diagnosis of microenvironments. Below is a list of additional tools that may be useful to any environmental management team. Some of these may already be available through one of the team partners; teams may identify others that would be helpful as they progress through the methodology.

Infrared Temperature Gun (IR Gun)

Infrared guns are a relatively cheap tool to have on hand for spot-checking temperature. These instruments are designed to measure temperature only; they do not measure relative humidity or moisture content. While IR guns should not be used as a sole means of measurement they are an excellent tool to check hard to reach spaces, potential microclimates, or to show evidence of temperature stratification in a space. They are often available online or in local hardware stores for around $50-$100. Be sure to check the specifications on the instrument before purchase and aim to find a unit that is accurate to at least +/- 3°F.

Thermometer

A traditional thermometer is still a useful tool for monitoring a collection space. Some collection spaces do not have thermostats with digital displays where team members or staff can quickly check the temperature in a location, and dataloggers may not be an option for every room/space/location. Thermometers provide an inexpensive way for collection staff to visually monitor the temperature in a space. Like the IR gun this should not be used as a sole means of measurement, but when placed around a collection space can provide a quick initial reading to alert staff to potential issues. This can be especially useful in spaces that have had past issues or in significant or at-risk collections areas. Check for accuracy specifications when purchasing digital thermometers, and aim for the most accurate option that fits the budget. One key benefit to thermometers is the cost – many can be purchased for less than $5-$10.

Thermal Imaging Camera

Until recently, a thermal imaging analysis of a building or space was a significant undertaking. An institution would either need to hire a consultant or purchase their own thermal imaging camera – options that could be both time consuming and expensive. The thermal imaging camera market has started to offer smaller versions of equipment, including cameras that connect and communicate with many smartphone brands. These cameras allow smartphone users to take thermal images and temperature readings. A thermal imaging camera can be used to provide an initial analysis of the building envelope, find areas where cold or warm air may be leaking into the facility, potential microclimates, or areas where moisture may be collecting. Basic interpretation and analysis is fairly straightforward – users do not need to be particularly experienced to operate the camera or to decipher the most basic results. The average price for a thermal imaging camera for a smart phone is $200-$250.

Camera

You can never have too many pictures of the collection spaces, mechanical rooms, or air-handling units. Part of the challenge of forming an environmental management team is bringing individuals with different backgrounds to a common level of knowledge regarding the collection, building operation, and the mechanical system operation, and images are an immense aid in that process. Photo documentation is also critical for incident tracking of preservation and mechanical operation, showing the location of dataloggers, illustrating airflow or mechanical design issues or flaws, and having a common image that the team can utilize without always going back to a unit or space. Images become particularly useful during data analysis, providing a visual aid to graphed data. Smartphone or point-and-shoot cameras will often suffice for the team's needs. Be sure that images are accessible to the team via a shared network folder or site.

Drawings/Blueprints

While already addressed in the documentation section, building drawings and blueprints are a useful tool to have on hand throughout the methodology process. Availability will vary by institution. The best resource to contact first in this regard is the facilities department or the building operations manager – sometimes original drawings will even reside with the institutional archives. Accuracy is not a given; even as-built drawings may include features that were never constructed or installed, and documents such as sequences of operation and individual pieces of equipment may have changed drastically since the original installation. The goal is to be able to work with the most accurate set of drawings possible for the building – even if the team has to "create" these based on multiple versions or resources. In the event of unreliable prints and drawings, some institutions have even gone so far as to commission new "as-builts" from architects and engineers to document the current state of their facilities.

Keep in mind that drawings and blueprints may be covered under some institutions' security policies, and may not be easily available to non-facilities staff, or available for reproduction.

It is important to know the layout of the entire facility – remember, the goal is a holistic understanding of the preservation environment, which can often include not only adjacent but also seemingly unrelated spaces. Having an accurate set of blueprints to a facility will help determine air movement, distribution, and air-handling zones, physical layout and shared walls, and vertical arrangement (i.e., is the boiler room directly under the gallery?) among other aspects. Analyzing the blueprints may shed light onto some characteristics of the facility that were unknown, or may correct a misconception about the facility. The team should work on analysis together – facilities staff may have previous familiarity, but multiple pairs of eyes often help tease out information, and the entire team should be comfortable asking questions if they are unclear about what the drawings are showing.

A few general tips for analysis and use:

- Be sure the blueprints are the most recent set possible or 'as-builts'. This will increase the possibility that they are correct.
- Do not mark up the original drawings or blueprints, make copies of the prints.
- If no prints are available, try to use fire evacuation plans, floor plans, or basic hand-drawn maps to trace ductwork or to mark pertinent information.
- Don't be afraid to ask questions about the prints.

HVAC Schedule

The term "schedule," with regard to HVAC operation, can have two meanings. From the control perspective there is the daily operating schedule; from the design perspective the schedule refers to the design data for individual AHU components. While both are critical to understanding the operation of the system, the design schedule will be regularly accessed as a critical tool. Mechanical design schedules are usually included as part of the design documentation and are typically incorporated into the mechanical section of the drawings. These schedules will break down the capabilities of the air handling units as they were designed and, typically, installed (provided there were no equipment substitutions). Normal information found in these tables will be design CFMs, intended outside air quantities, cooling coil dew point capabilities, heating capabilities, and information about humidifiers.

Zone Maps

A zone map is a copy of a blueprint or building map that has been colored to identify which areas a specific AHU serves. Though they are gaining in popularity in facilities management, zone maps for many facilities will not exist and will need to be created by the facilities staff or the environmental management team. A zone map is created by tracing supply and return air ductwork to and from an AHU either on the mechanical drawings or by physically following the ducts through the facility and drawing them on a floor plan (Additional guidelines available in the Documentation section, *Creating Zone Maps*). Typically maps will be color-coded to identify which air handling unit, VAV, or reheat controls which area. Zone maps become incredibly useful to indicate which areas may be affected by experimental tests or changes that may be made to an AHU's operation. The process of creating zone maps may also illustrate areas served by an AHU that were previously unknown.

Building Management System (BMS)

A building management system or BMS is a computer platform that controls and manages air handling systems and other aspects of a facility. If present in the institution, environmental management teams should strive to use the BMS to its best ability as a data and operational resource. Facilities team members can often set up a tour of software, what data it shows and collects, and how the sequence of operation and set points are manifested in the controls. The goal is to understand how the building controls work, what experimentation and testing may mean from the perspective of the BMS, and how to work smoothly with the institutional staff or contractors responsible for using and managing the system. As work through the methodology progresses and communications and relationships grow stronger, teams may be able to get read-only access to check on operating conditions for collections environments. Checking BMS data can help to identify causes of any issues and function as an early warning system.

DPcalc.org

The Image Permanence Institute's Dew Point Calculator (www.dpcalc.org) is an excellent free tool that incorporates psychrometric relationships between temperature, relative humidity, and dew point into a user-friendly, slider-based interface. The site allows a user to select combinations of temperature, relative humidity and dew point, and will apply the Preservation Metrics algorithms to determine potential degradation risks (chemical decay, mechanical damage, mold, and metal corrosion) at those conditions. The site helps users evaluate how current set points may impact the collection, and how proposed set point changes may alter preservation quality or risk. It can be particularly useful to the environmental management team as a planning tool to discuss the impact of various environmental conditions that may be tested or designed.

eClimateNotebook.com

While most datalogger brands offer software solutions that provide some level of graphing, basic data analysis, and viewing tools, very few incorporate materials degradation research into the package. eClimateNotebook was designed specifically for use by cultural institutions, and uses IPI's Preservation Metrics to provide initial preservation analysis for environmentally-induced risks. Features vary depending on the subscription level that is chosen. The platform can ingest data from most brands of dataloggers, will generate reports highlighting preservation risks and illustrating environmental data, and can help clearly communicate environmental conditions and their potential consequences to members of the environmental management team as well as institutional administration.

Outdoor Weather Data

Normal operation of most air handling systems involves the use of at least some outside air intake into the building. This influx can often account for the vast majority of moisture control and pollutant filtration that the system has to perform, so knowing the condition of the outside air (temperature, relative humidity, dew point) can be critical for both data analysis and diagnosing certain system performance issues. Sources can range from data available through a BMS, dataloggers placed in the outside air intake, or recorded data through platforms such as eClimateNotebook. Work to ensure that the source is accurate and reliable for the actual building site. The goal is to be able to compare outdoor and indoor environmental trends to analyze mechanical systems and building envelope performance.