IPI's Methodology for:

Implementing Sustainable Energy-Saving Strategies

in collections environments

IMAGE PERMANENCE INSTITUTE

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This project was designed to formulate a proven approach to achieving sustainable mechanical system operation, without sacrificing preservation quality, into a methodological guide for use by individual libraries, archives, museums, and other cultural institutions.

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INTRODUCTION

In 2012, the Image Permanence Institute (IPI) published *IPI's Guide to Sustainable Preservation Practices for Managing Storage Environments* as part of a successful National Endowment for the Humanities (NEH) Education and Training grant to present information about defining and achieving optimal and sustainable preservation environments. This program, the first of three funded through NEH, enabled IPI to reach hundreds of institutions around the United States and the world via a series of workshops and webinars, exposing collections professionals and allied colleagues to research and strategies that could allow for the achievement of the preservation mission while also participating in institutional sustainability efforts. However, conversations and field experience soon revealed that the *Guide to Sustainable Preservation Practices* was only one of the necessary resources – while it addressed the "what you need to know" and "what you need to do" aspects of sustainable preservation, the critical aspect of "this is how you do it" was still missing.

During the same time period, IPI was conducting research into scheduled, risk-managed shutdowns of mechanical systems that served collections environments as part of an Institute of Museum and Library Services (IMLS) National Leadership Grants for Libraries project entitled "Research on Energy-Saving Opportunities in Libraries." The premise was to show whether scheduled shutdowns – which had been used for years as a common energy-reduction strategy in commercial buildings – could be safely used in a collections preservation environment. Research showed that most buildings and environments could withstand carefully managed shutdown periods ranging from a few hours to eight hours per night, but equally as important, the research gave IPI and our partners an opportunity to think about the criteria and process involved in determining whether an environment may be a good candidate for a shutdown before testing even began. These ideas were further solidified through the experience gained in our environmental consulting practice.

This resource is designed as a companion volume to IPI's Guide to Sustainable Preservation Practices for Managing Storage Environments.

This publication will take you from the "what you need to know" and "what you need to do" focus of the original Preservation Practices Guide to a more specific "this is how you do it" approach.

The methods that we have developed, through years of research and consulting at IPI, and decades of experience working on energy–saving practices with Peter Herzog of Herzog/ Wheeler & Associates in St. Paul, MN, are presented in this Guide.

Our hope is that the methodology and resources provided here will allow institutions to implement sustainable practices and achieve optimal preservation environments on their own.

In 2013, IPI applied to IMLS with a proposal to create a second, companion resource to the 2012 guide that would walk libraries, archives, museums, and other cultural organizations through the risk-laden process of exploring energy-savings work in collections-holding facilities. The proposal was successful, and IMLS provided funding for a demonstration project entitled "Demonstrating a Sustainable Energy-Saving Methodology for Library Environments" through the National Leadership Grants for Libraries program. The premise was simple – to take the successful consulting and field work practices developed at IPI with our partners and formulate them into a written methodology, the "how to do it," based on experience.

The implementation of sustainable preservation programs in cultural institutions has often required the involvement of outside consultants throughout the process – from documentation and data-gathering through testing, implementation, and maintenance. Institutions, while interested, have been limited by the availability of grant funding or their own capacity to afford external assistance. By providing a clearly written methodology, with step-by-step processes, tips, resources, and tools, the hope is that institutions will be empowered to take greater ownership of implementing sustainable preservation practices.

The project itself was designed with two key activities – the writing of *IPI's Methodology for Implementing Sustainable Energy-Saving Strategies in Collections Environments*, and the field-testing and demonstration of its viability to end-users. After an application process, three partner institutions were selected for the field test. The goal was to find partners from a variety of climate, building, mechanical, and institutional types who had already been gathering data about their preservation environments and were prepared to take the next steps.

All three institutions utilized the energy-saving strategies differently, and had quite distinctive experiences over several years of implementation. One partner came into the process with a strong sustainability track record elsewhere in their institution – they needed a process that would allow them to perform energy work in their collections environment. In the end, they were able to use the process to implement night-time mechanical shutdowns in a library collections space.

Another partner was a museum library that was testing two storage areas of different eras/construction, and each with a different mechanical system design. In one building, they were able to implement seasonal shutdowns, discover unnecessary winter dehumidification operation, and document mechanical issues that they had been trying to explain for several years. In the second building, they implemented new seasonal set points and a year-round night-time shutdown, resulting in both energy-savings and improved seasonal preservation quality.

The third partner faced their own challenges: a nearly century-old academic library building located in the American deep south, their Preservation Librarian accepting a new position with another organization in the midst of the process, and the other two team members – one each from library administration and campus facilities – tasked with significant normal responsibilities. In the end, though initial testing showed the potential for several strategies to be implemented, facilities staff downsizing and controls issues halted the mechanical testing and the institution chose instead to focus on improving lighting operation and efficiency.

The partners' experiences varied greatly, yet illustrated precisely the purpose behind creating this guide – to provide institutions with a procedure to guide them through the discovery of opportunities, help them avoid risk to collections, and adopt optimal practices that are appropriate to their own situation, capacity, and needs. Some organizations with the appropriate infrastructure, energy, and mandate will be able to use this guide to implement three, four, or maybe more strategies that fit their situation and goals; others may implement one. Still others may not make any operational changes, and will use the methodology outlined here to document preservation conditions or operation in order to plan for future projects, or to confirm that the current operation is the best they can manage without external help. All of these scenarios are successes – when looking at sustainable preservation, success is any progress toward your goal, even if it is simply learning what will not work, or cannot currently be done.

THE GOAL:
An "optimal preservation environment" – an environment that provides the best possible preservation of collections at the least possible consumption of energy and is sustainable over time.

The question is how to go about safely achieving the seemingly disparate objectives of maintaining or improving the preservation quality of collection environments while reducing the energy used to create the environment.

Preservation professionals have long understood, and research has shown, that temperature and relative humidity (RH) are significant factors that impact the lifespan of collections materials held by cultural institutions. However, the mechanical systems that have been designed and installed to create and control appropriate preservation environments often represent a significant portion of the energy used by, and the total budget of, cultural institutions. With limited resources and an awareness of the environmental and energy costs of operation, cultural institutions must now continue to provide quality preservation environments but do so in a sustainable manner.

IPI's general approach to providing an optimal preservation environment focuses on three core principles:

1. Preservation of collections requires specific conditions, but that these conditions can, and often should, vary, particularly seasonally. The previously accepted standard (an unwavering 70°F/50%RH) for collections storage environments is not ideal, and a holistic and flexible approach to environmental management is more successful.

2. Most mechanical systems operate sub-optimally and this type of operation is not self-announcing. Institutions operate on a fine line when it comes to resources and time allocation – attention is given first to those things that are known to be broken. A system that is achieving its environmental goal, even through sub-optimal operation, is rarely diagnosed as broken, and it takes proactive inspection to discover the inefficiency.

3. The simultaneous achievement of both the best preservation and optimal system operation is a process that requires a series of carefully defined, risk-managed steps that serve to test individual strategies in order to come to a final strategic approach for a unique collection, space, and mechanical system.

Our experience and practice have shown us that, while there is no single solution that will work for every institution, there are a series of practical energy-saving strategies that, with testing and assessment, will work in some combination for nearly any institution that holds library or cultural materials without endangering those materials.

This guide is designed to help institutions discover the best intersection between collection preservation and energy-savings for themselves, accounting for the unique factors at every institution.

These factors include the:

- Geographic and climate region the institution is located in;
- building construction and envelope;
- specific preservation needs and characteristics of the collections stored in various locations within the building;
- design capabilities of the mechanical systems in place; and
- the skills and abilities of institutional collection care and facility management staff.

The Process of Optimization

A good optimization process is highlighted by two key underlying factors:

- Dedication to an analytical approach that is based on risk analysis and mitigation; and
- an understanding that the process of optimization requires experimentation and analysis – not simply making changes.

IPI's Guide to Sustainable Preservation Practices for Managing Storage Environments described the optimization activities of the environmental management team in six steps:

1. Document the capabilities and performance of your HVAC system
2. Define the environment that is best for collections
3. Determine the environment acceptable to occupants
4. Negotiate the optimal environment for each storage area based on the information gathered during steps 1 through 3
5. Express the optimal environment in measurable metrics
6. Regularly measure the "actual" environment, compare those results to the "optimal" environment you have defined, and promptly correct any malfunctions

Early steps in this process inform the later experiments and strategies and serve as a long-term resource for the institution as a whole. It is important to remember that the results of experimentation are only applicable given the current system and building characteristics. Major renovations, system updates, or re-purposing of space may render previous experimentation inaccurate.

This guide breaks down each of these steps a little further and lays out specific procedures for the team to follow during five primary activities:

1. Documentation
2. Gathering Environmental Data
3. Data Analysis
4. Experimentation and Implementation
5. Assessment and Maintenance

Optimization is an interactive process - the team may work through the five activities for one strategy, and then go back and repeat steps four and five to test a new strategy, or a new or upgraded piece of equipment may require revisiting steps three, four, and five to see whether its optimal operation is similar to the previous setting. If an optimization study was conducted five years ago, it is a good idea to revisit steps two and three to discover whether the system and space are still functioning as the team intended since an event (controls upgrade, major power outage, or an undocumented change) could have altered the mechanical operation without changing the space condition.

Developing the Environmental Management Team

Teamwork is an essential part of sustainable environmental management. Balancing the preservation quality of the storage environment with responsible building management and lower energy costs requires shared effort, knowledge and expertise, as well as regular communication among colleagues. It is a process, not a project, requiring a sincere long-term commitment from a team of stakeholders.

In most cases the people who affect the climate in collecting institutions are numerous and not usually connected by an organizational structure. These individuals may include:

- People who provide/create the environment
- People who are responsible for preservation of collections
- People who work in and around collections
- People who are responsible for administration and finances
- People who direct the sustainability mission and goals

Working together, representatives of these groups can provide a holistic understanding of what the collections need, what the HVAC systems are capable of, the comfort requirements of occupants, what the institution can afford, and what its sustainability mandates and policies may be.

Team Roles and Responsibilities

Collections staff are responsible for the care and management of collections, loans, and associated documentation. Management of the environment for long-term preservation of collections is an important aspect of collection stewardship.

The collection representatives need to know:

- What collections and material types the institution holds;
- what the most pressing deterioration risks are;
- which collections are vulnerable to environmentally-induced damage;
- what the environmental conditions are and what they should be; and
- how these conditions affect collections.

Facilities staff are responsible for all aspects of building management, and can include architects, engineers, controls designers, facility managers, building operators, and maintenance staff. The facilities representative(s) should:

- Understand the mechanical system functions and capabilities;
- provide mechanical system documentation and history;
- have knowledge of or access to building envelope information and construction details; and
- have the authority to carry out team decisions.

Administration is responsible for the overall management of staff needs, collection stewardship, institutional priorities and budgets. Although not necessarily active in all team meetings and activities, the administrative representative should:

- Encourage and support team goals and activities;
- place team activities within the larger institutional context as they pertain to budgets and operation; and
- provide necessary resources.

Sustainability officers are becoming more common in institutional administration and are typically responsible for broad sustainability and energy goals. A sustainability representative should:

- Know the current sustainability initiatives within the institution;
- share any existing mandates for energy or carbon-footprint reduction;
- provide examples of any similar efforts they are aware of; and
- communicate the efforts of the environmental management team to other groups, including the process, successes, and lessons learned.

Team members will be expected to:

- Collect and review environmental data from collection and exhibition spaces;
- document the capabilities and performance of the HVAC systems that serve these spaces;
- define the optimal environment—one that is best for collections, acceptable to occupants, achievable with current equipment, and energy-efficient;
- meet regularly to review and analyze data, and compare the actual environment to the optimal as defined; and
- identify and test options for improvement.

Creating Buy-In

Everyone is busy and people rarely get excited about more meetings and new responsibilities. However, our experience has shown that, with patience and commitment to the process, team management of the environment will result in more efficient use of staff time, improvements in system operation, better preservation quality, and very often considerable energy saving. Benefits can go beyond the specific task of sustainable preservation – by bringing together colleagues who may not regularly interact, professional relationships are strengthened and communication across the organization is improved, often providing gains in team members' day-to-day responsibilities.

WITH EFFECTIVE TEAM MANAGEMENT AND REALISTIC T & RH PARAMETERS YOU CAN:
Define sustainable preservation and operational goals together
Reduce operational inefficiencies
Develop a clear path to problem resolution
Identify energy-saving opportunities and meet sustainability goals
Reduce the cost of providing heat, ventilation, cooling, and lighting
Reduce the time spent responding to short-term fluctuations in T and RH
Reduce the number of human comfort calls
Improve communication and understanding between collection and facility staff

Kick-Off Meeting

Effective team management requires a team leader, someone to champion the cause, convene meetings, and encourage participation. With administrative support, team leaders should call potential representatives together to gauge interest and recruit active participants. The roles, responsibilities, activities, and time commitments can be outlined in a kick-off meeting. Once an environmental management team is established, the five steps detailed in the methodology can begin.

While sustainable preservation is often brought to attention by staff responsible for collections preservation, the team leader can come from any place within the organization – collections professionals, facilities staff, and administrators have all successfully shepherded these efforts. The key is recognizing that each potential team member is coming to the group with their own job responsibilities and priorities that they have to accomplish. A successful kick-off meeting will place sustainable preservation in the context that is critical for each potential participant. Examples of this may include:

- Collections professionals may achieve better preservation conditions if opportunities for altered set point control are discovered.
- Facilities staff have the opportunity to fine-tune control of the system, identify components that may not be operating properly or may need to be replaced, or generally educate the team about the building operation.
- Administrative and sustainability staff may value the opportunity to include the collections areas in the institutional sustainability mission or in energy-reduction efforts, or may value the educational or public relations opportunities that go along with new initiatives.

Though sustainable preservation may be enough incentive on its own to bring a potential team together, the kick-off meeting should include an introduction to the idea of sustainable preservation and an optimal preservation environment, and will often include a discussion of the factor or factors that make the process appealing. Budgetary concerns, damaging environmental conditions, pressure to participate in energy-reduction efforts, or simple administrative mandates are all examples of potential driving forces behind sustainable preservation efforts.

Much like an integrated design process in building construction and design, the environmental management team relies on having the right voices at the table from the very outset of the process – all perspectives are considered, and the optimal preservation environment will often be a negotiation and compromise among the members of the group.

Moving the Process Forward

Once the environmental management team has been established, the next step is moving into the methodology process. You may choose to begin going through the documentation phase as part of the kick-off meeting, or to reconvene the group again after everyone has had a chance to look through the process.

Our experience has found that teams work best when they meet an average of once a month – with busy schedules and short-staffing common, a month is often a reasonable time frame. Teams will often choose to meet more frequently at the outset of the process, or during periods of experimentation and testing.

When staff changes occur, it is the responsibility of the team to recruit and bring a new member up-to-date on the current activities. This becomes easier the longer the team has been established, and is one of the underlying goals of the process – to make the environmental management team a part of the regular institutional work flow.

INTRODUCTION: SAFETY PRECAUTIONS

Mechanical rooms and air-handling units will be unfamiliar territory for many on the environmental management team. Like any area with operating machinery, safety is the first priority. Let the facilities staff be your guide, follow their instructions, and learn from their experience. The following are a few tips to keep in mind.

When working around or with Air Handling Units (AHU)

1. Always follow your facility's safety procedures.
2. Follow the buddy system, and always have a facility or HVAC representative on hand.
3. Always carry a flashlight and your cell phone.
4. Leave everything in the unit as you found it.
5. Be aware that some mechanical rooms can be small and your mobility may be limited.
6. Many mechanical rooms have low pipes or ductwork inside. Always watch your head inside of a mechanical room.
7. Many mechanical rooms have plumbing running along the floor. Be sure to watch your step when navigating a mechanical room.
8. Mechanical rooms can be noisy. Be sure to have the proper hearing protection if necessary.
9. Keep your hands and feet away from any moving parts. Be aware of any loose clothing or accessories.
10. Do not touch any part of the unit you are not familiar with. If you have the authority to enter the unit:
    a. Watch your head when entering or exiting any unit.
    b. Ensure the units are turned off before opening any access door.
    c. While inside of any chamber, be aware of any screws or nails that may rip or tear clothing or could cause physical harm.
    d. Be careful of where you place your hands – fins on heating and cooling coils, edges of dampers, and other parts of the unit can have sharp edges.
    e. When opening any access door, be sure not to wear any loose or dangling items (i.e. ties, lanyards, scarves, necklaces, etc.) as these items may be pulled downstream by the air or become entangled in the fan or motor.
    f. Be careful when working in or around a humidifier – the lines may be hot and can burn very quickly, and steam discharge can easily scald. If the system is still operating, there is the possibility that the humidifier may operate while you are working near it.
11. Do not leave any foreign objects inside the units (ladders, cups, tools, wrappers, etc.).
12. Do not attempt to make any changes or adjustments to the units on your own.
13. If any issues are noted with a unit do not attempt to repair them. Report the issue to a facilities representative as soon as possible.
14. Always turn the system back on when you are done.

Air Handling System

Components/Layout:

A: Dampers

B: Filters

C: Cooling Coil

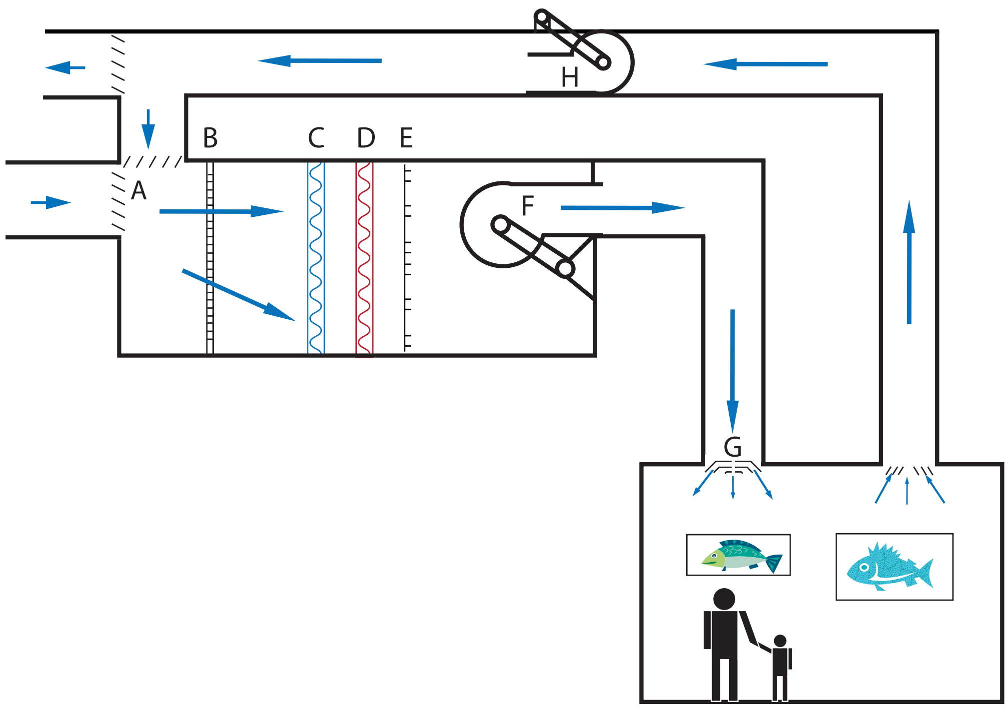
D: Heating Coil

E: Humidifier

F: Supply Fan

G: Diffusers

H: Return Fan



Air Flow:

Air enters the system from the outside through an air duct and is mixed just before the filters with return air from the space. The mixed air is pulled through a set of filters (B) where impurities like particulates and gaseous pollutants are removed. As the air moves forward, it passes over a set of cooling coils (C), where the air is cooled, and depending on the dew point of the passing air, may be dehumidified. The air then passes over a set of heating coils (D) where it is heated to the required temperature if necessary. Following the heating coil the air will pass over a set of humidification tubes (E). If the relative humidity of the passing air is too low these tubes will add moisture to the air as it passes. After the humidifier, the air is pulled into the supply fan (F), which then pushes it through the supply ductwork, through the diffusers (G) and into the space. The return fan (H) pulls air from the space and pulls it through the return ductwork. Finally, the air is either exhausted to the outside or returned to the unit to be mixed with new outside air and start the cycle all over again.

Refrigerant/Heating Supply:

The cooling coils are fed from a source of cooling, such as chillers, a cooling tower, or DX unit. The refrigerant enters the cooling coils, absorbs heat from the air passing the coils, and returns to its source to desorb the heat that it took in. The heating coils are fed from a heat source such as a boiler or electricity. The heat from these coils is transferred to the air passing over it.

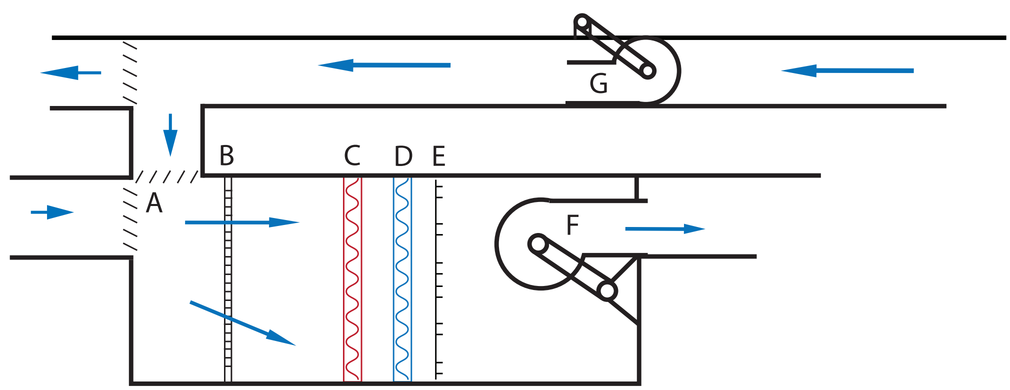
System Variations:

1. A system may have multiple sets of filters to remove different levels of impurities.
2. The arrangement of the cooling coil and heating coil may vary from unit to unit.
3. A cooling coil may not be present in every unit or may be before the outside air dampers for pre-cooling.
4. A heating coil may not be present in every unit.
5. The main heating coil may be farther down the line in the ductwork in what is called a reheat. As a reheat the coil will heat air for a specific space just before it is discharged from the ducts.
6. A system may utilize a bypass setup where the air can be diverted past the coil(s) if it does not need to be treated.
7. Humidification tubes may not be present in every unit or may be farther down in the ductwork just before the diffusers.
8. A return fan may not be present on every unit if the supply fan creates enough of a draw to pull the air back through the space.

Heating/Cooling System

Components/Layout:

A: Dampers
B: Filters
C: Heating Coil
D: Cooling Coil
E: Humidifier
F: Supply Fan
G: Return Fan



Air Flow:

This type of unit is most common in environments where moisture removal from the air is not much of a concern. Starting at the outside air intake, air enters the outside air duct and is mixed with return air from the space just before the filters (B). This mixed air is pulled through a set of filters where impurities are removed. The air then passes over a set of heating coils (C) where it is heated to the required temperature if necessary. Next the air passes over a set of cooling coils (D); here it is sensibly cooled to the desired temperature if necessary. After the cooling coil the air passes over a set of humidification tubes. If the relative humidity of the air is too low these tubes will add moisture to the air as it passes. After the humidifiers, the air is pulled into the supply fan (F), which pushes it through the supply ductwork, through the diffusers and into the space. The return fan (G) will pull in air from the space and push it through the return ductwork. The air is either exhausted or returned to the unit to be mixed with outside air and start the cycle all over again.

Refrigerant/Heating Supply:

The cooling coils are fed from a source of cooling, such as chillers, a cooling tower, or DX unit. The refrigerant enters the cooling coils, absorbs heat from the air passing the coils, and returns to the source to desorb the heat that it took in.

The heating coils are fed from a heat source such as a boiler or electricity. The heat from these coils is transferred to the air passing over it.

System Variations:

1. A system may have multiple sets of filters to remove different levels of impurities.
2. A cooling coil may be before the outside air dampers for pre-cooling.
3. The system may utilize a bypass setup where the air can be diverted past the coil(s) if it does not need to be treated.
4. Humidification tubes may not be present in every unit or may be farther down in the ductwork just before the diffusers.
5. A return fan may not be present on every unit if the supply fan creates enough of a draw to pull the air back through the system.

Preheat System

Components/Layout:

A: Dampers

B: Filters

C: Cooling Coil

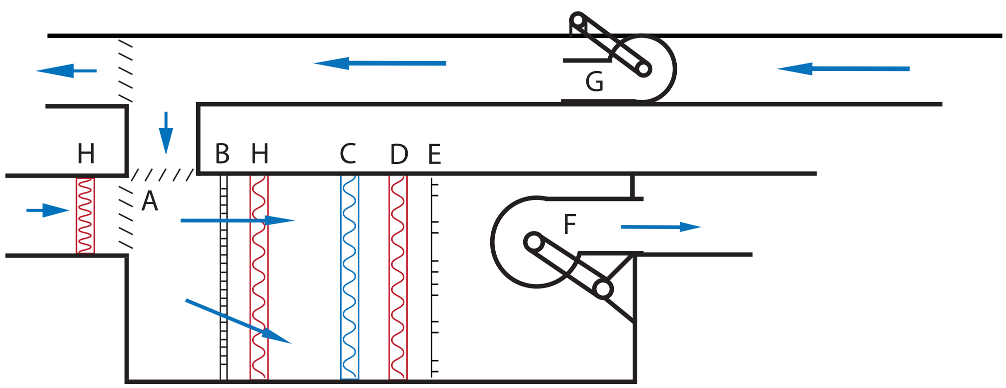
D: Heating Coil

E: Humidifier

F: Supply Fan

G: Return Fan

H: Preheat Coils



Air Flow:

This system is a standard air handling unit that utilizes a preheat coil (H). This coil should only operate during the winter months, if the outside air is below freezing. The goal of this coil is to preheat the incoming outside or mixed air to prevent the cooling coil (C) from freezing. These units are typically found in colder regions where there is greater risk of low winter temperatures. Starting at the outside air intake, air enters the outside air duct and is heated by the pre-heat coil. The air is then mixed with return air from the space just before the filters (B). This mixed air is pulled through a set of filters where impurities are removed. As the air moves it passes over a set of cooling coils (C), here the air is cooled and depending on the dew point of the passing air, may be dehumidified. The air then passes over a set of heating coils (D) where it is heated to the required temperature if necessary. Following the heating coil the air will pass over a set of humidification tubes (E). If the relative humidity of the passing air is too low these tubes will add moisture to the air as it passes. After humidification, the air is pulled through the supply fan (F), which will push it through the supply ductwork, through the diffusers and into the space. The return fan (G) then pulls in air from the space and pushes it through the return ductwork. The air is either exhausted or returned to the unit to be mixed with outside air and start the cycle all over again.

Refrigerant/Coolant Cycle:

The cooling coils are fed from a source of cooling, such as chillers, a cooling tower, or DX unit. The refrigerant enters the cooling coils, absorbs heat from the passing air, and returns to its source to desorb the heat that it took in.

The heating coils are fed from a heat source such as a boiler or electricity. The heat from these coils is transferred to the air passing over it.

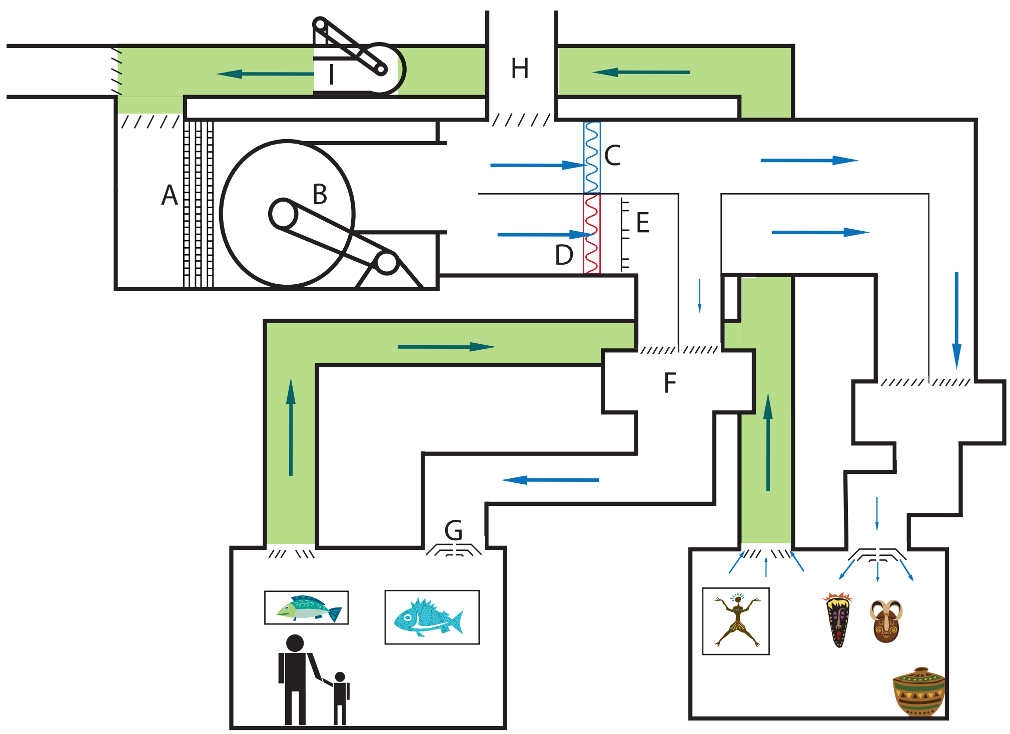
System Variations:

1. A system may have multiple sets of filters to remove different levels of impurities.
2. The preheat location may be directly at the outside air intake or after the mixed air chamber.
3. The main heating coil may be farther down the line in the ductwork in what is called a reheat. As a reheat the coil will heat air for a specific space just before it is discharged from the ducts.
4. A system may utilize a bypass setup where the air can be diverted past the coil(s) if it does not need to be treated.
5. Humidification tubes may not be present in every unit or may be farther down in the ductwork just before the diffusers.
6. A return fan may not be present on every unit if the supply fan creates enough of a draw to pull the air back through the space.

Dual Duct Air Handling Unit

Components/Layout:

A: Filters
B: Supply Fan
C: Cooling Coil
D: Heating Coil
E: Humidifier
F: Mixing Box
G: Diffuser
H: Outside Air
I: Return Fan



Air Flow:

Starting at point A on the diagram above, return air passes through the filters on the system and is drawn into the supply fan. The air is then pushed into the dual duct section of the unit. It will now separate into two ducts, one that will handle the heating functions and one that will handle the cooling functions:

Route One/Cooling – Air enters into the cooling duct (C). Here the air is mixed with outside air. This air now becomes a mixed condition of return air and outside air and passes over the cooling coil. Here the air is cooled and, depending on the dew point of the passing air, may be dehumidified. After passing over the cooling coil the air will proceed through the ductwork and be mixed with the heated air in a mixing box (F).

Route Two/Heating – Air enters into the heating duct (D). Here the air will pass over a set of heating coils that heat the passing air. Next it passes over the humidifier. If the relative humidity of the passing air is too low the humidifier will add moisture to the air and will continue moving through the ductwork towards the mixing box (F).

At the Mixing Box – The mixing box is the location in the ductwork where the heating and cooling ducts combine. Here the heated air is mixed with cooled air to achieve the desired temperature for the space. The mixing of air is controlled by a sensor that adjusts dampers on the entering heating or cooling air, opening or closing them, to ensure that the right mix of air is used to create the desired supply temperature.

After the mixing box, the mixed air continues down the ductwork. The air passes through the diffuser (G) and enters the space. Eventually the air is drawn back into the return ductwork and pushed through the return fan (I). From here it will either be exhausted or returned to the start of the system to begin the process again.

Refrigerant/Heating Supply:

The cooling coils are fed from a source of cooling such as chillers, a cooling tower, or DX unit. The refrigerant enters the cooling coils, absorbs heat from the passing air, and returns to its source to desorb the heat that it took in.

The heating coils are fed from a heat source such as boiler or electricity. The heat from these coils is transferred to the air passing over it.

System Variations:

1. An outside air duct can be found either before the cooling coil or before the filters on the air handling unit, depending on the design.
2. A system may have multiple sets of filters to remove different levels of impurities.
3. If the outside air duct is before the cooling coil the filters may be located before the outside air damper or cooling coil to treat the new air coming into the system.
4. A system may utilize a bypass setup where the air can be diverted past the coil(s) if it does not need to be treated.
5. Humidification tubes may not be present in every unit. A humidification coil may also be present after the cooling coil.
6. A return fan may not be present on every unit if the supply fan creates enough of a draw to pull the air back through the space.

Variable Air Volume (VAV) System

Components/Layout:

A: Heating Coils

B: Air Flow Sensor

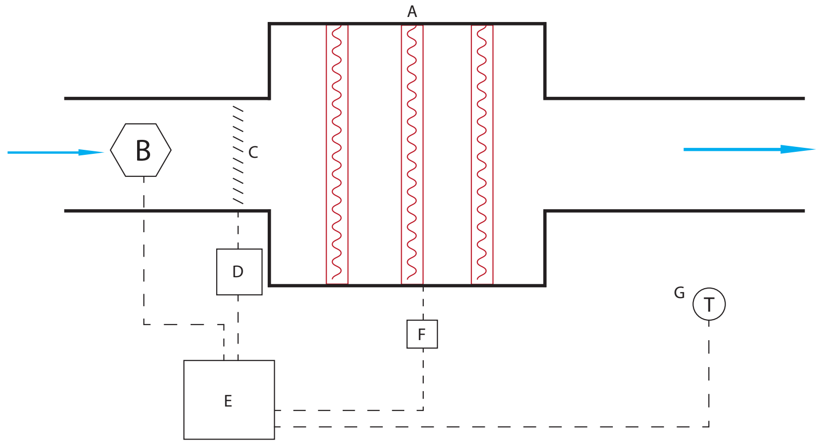
C: Dampers

D: Actuator

E: Controller

F: Contactors

G: Thermostat



Air Flow:

VAV stands for variable air volume, and VAV boxes may be a part of an air handling system. They are located in ductwork before the air reaches a designated space. Primary air from the air handling unit is pushed downstream to a VAV box. Just before the VAV box there are a set of dampers (C). These dampers are controlled by an air flow sensor (B) or a space thermostat (G) that will command the actuator (D) to open or close to adjust the volume of air that is pushed across the heating coils (optional). When air enters a VAV the heating coils inside will heat the air if necessary. As the air is heated it is pushed out of the VAV box and delivered to the space as secondary air. If no heating is required the contactor will not activate the heating coils and the air passes on with no heating.

System Variations:

1. A heating coil may not be present in every unit.
2. A fan may be located inside the VAV to increase air velocity when air volume is low.
3. In some cases a humidifier may be present.

Direct Expansion (DX) Individual Air Conditioning System

Components/Layout:

A: Condenser Coil

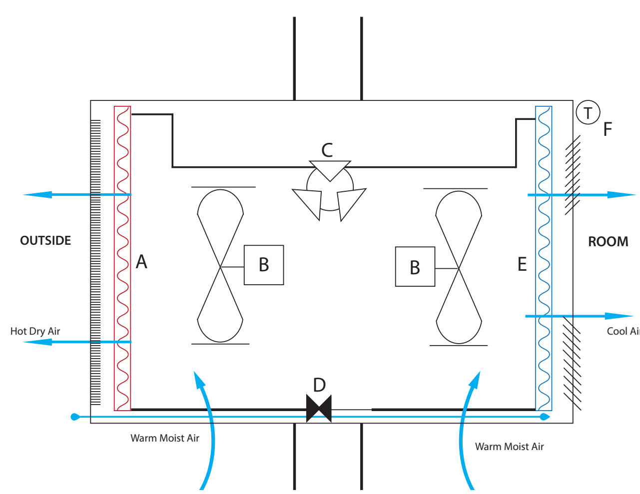
B: Fans

C: Compressor

D: Expansion Valve

E: Evaporator Coil

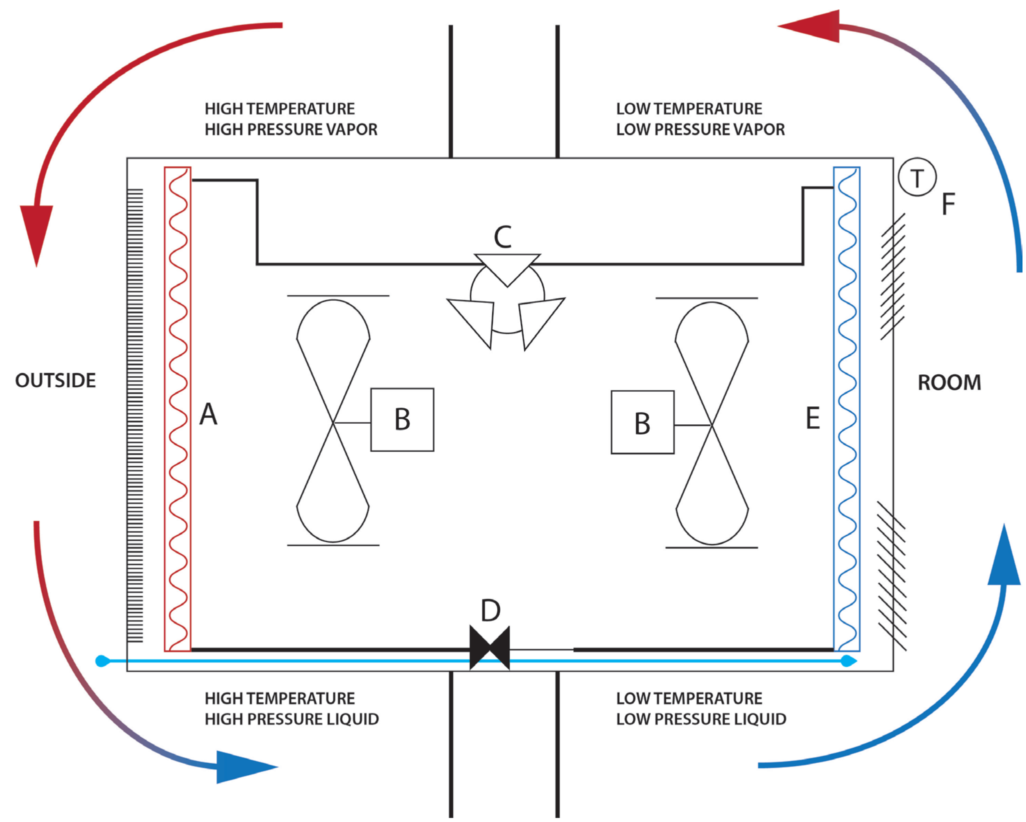
F: Thermostat



Air Flow:

Inside the space air is drawn in through the sides of the unit. This air is pushed across the evaporator (cooling) coils where it is cooled to the desired temperature for the room and pushed out the dampers on the front of the unit. The system is designed to sensibly cool the passing air, any dehumidification that may occur is a byproduct of this action. As the air is treated it may lose some of its moisture in the process, but the exiting cooler air will have higher relative humidity than the entering air.

On the outside portion of the unit, outside air is drawn in from the sides of the unit. This air is pushed by a fan across the condenser coils where the passing air will absorb the heat from the coils and be expelled out the rear of the unit. The expelled air will be hotter and drier than the outside air.



Refrigerant/Coolant Cycle:

Beginning just after the expansion valve (D) the refrigerant starts off as a low temperature, low pressure liquid. Under this low pressure condition the refrigerant has a low boiling point. The refrigerant is pushed through the evaporator coil (E) where it absorbs heat from the warm air that is passing over the coils. The heat absorbed by the warm air causes the refrigerant to boil and become a vapor. The refrigerant continues through the system toward the compressor (C). As it enters the compressor the refrigerant is now a low temperature, low pressure vapor.

The refrigerant enters the compressor where it is pressurized into a high temperature, high pressure vapor. The refrigerant is now under very high pressure and has a high boiling point. At these conditions, the refrigerant can condense easily. As the refrigerant moves through the condenser coil (A) the fan inside the unit is pushing air across the coils. The refrigerant will expel heat to the passing air as it is pushed though the fins by the fan. The passing air will absorb the heat, causing the refrigerant to cool and condense into a liquid. The high-pressure liquid moves towards the outlet of the condenser, the expansion valve (D). The refrigerant will enter the valve as a high temperature, high pressure liquid. The valve will allow the pressure of the refrigerant to change and the refrigerant will exit the valve as a low temperature, low pressure liquid and start the process over again.

Note:

"Cold" is not created in this process. Refrigerant was used to transfer heat from the inside air to the outside air.

System Variations:

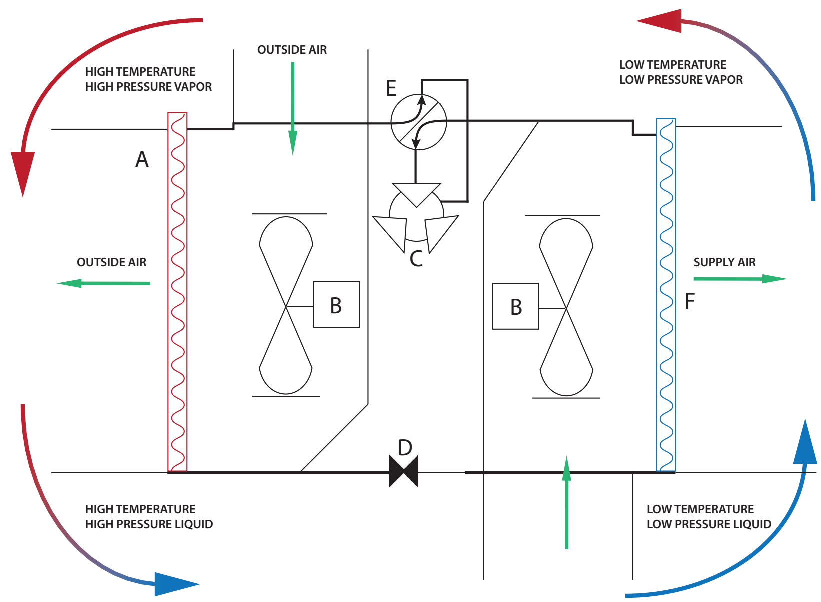
1. Unit may be a stand-alone air conditioning unit with a ducted exhaust.
2. Filters may be located on the sides of the unit to treat the incoming air.

Heat Pump

Components/Layout:

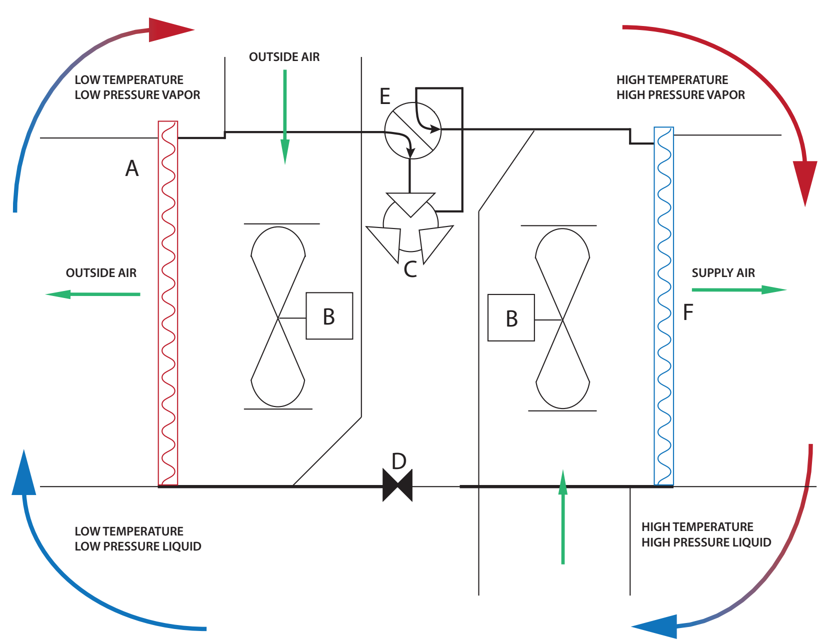
(Cooling Mode Diagram A)

A: Condenser Coil
B: Fan
C: Compressor
D: Expansion Valve
E: Reversing Valve
F: Evaporator Coil



(Heating Mode Diagram B)

A: Evaporator Coil
B: Fan
C: Compressor
D: Expansion Valve
E: Reversing Valve
F: Condenser Coil



Air Flow:

The system operates similar to the way a DX air conditioner works. The major difference is that it is capable of reversing the flow of refrigerant. The reversal of flow makes the unit capable of heating or cooling a space.

Cooling Mode Diagram A:

Air is drawn into the system by the fan through a return duct from the space. The air is pushed across the evaporator (cooling) coil where the air is cooled and returned to the space through the supply ducts.

The condensing coil is cooled by a second set of ductwork that brings in outside air and pushes it across the condenser (heating) coil where the refrigerant desorbs its extra heat to the air. The air is then discharged out of the unit.

Heating Mode Diagram B:

Air is drawn into the system through the return duct from the space by the fan. The air is pushed across the condenser (heating) coil where the air is heated and returned to the space through the supply ducts.

The evaporator coil is treated by a second set of ductwork that will bring in outside air and push it across the evaporator (cooling) coil where the refrigerant absorbs heat from the air. The colder air is then discharged out of the unit.

Refrigerant/Coolant Cycle:

Cooling Cycle Diagram A:

The refrigerant in this cycle will move in a counterclockwise pattern, following the blue arrows in Diagram A for refrigerant flow in cooling mode. Beginning just after the expansion valve (D) the refrigerant starts off as a low temperature, low pressure liquid. Under this low pressure condition the refrigerant has a low boiling point. The refrigerant is pushed through the evaporator coil (F) where it absorbs heat from the warm air that is passing over the coils. The heat absorbed by the warm air causes the refrigerant to boil and become a vapor. The refrigerant continues through the system toward the compressor (C), note the position of the reversing valve. As it enters the compressor the refrigerant is a low temperature, low pressure vapor.

The refrigerant enters the compressor where it is pressurized into a high temperature, high pressure vapor. The refrigerant is now under very high pressure and has a high boiling point. At these conditions, the refrigerant can condense easily. As the refrigerant moves through the condenser coil (A) the fan (B) inside the unit is pushing air across the coils. The refrigerant will expel heat to the passing air as it is pushed though the fins by the fan. The passing air will absorb the heat, causing the refrigerant to cool and condense into a liquid. The high-pressure liquid moves towards the outlet of the condenser, the expansion valve. The refrigerant will enter the valve as a high temperature, high pressure liquid. The valve will allow the pressure of the refrigerant to change and the refrigerant will exit the valve as a low temperature, low pressure liquid and start the process over again.

Heating Cycle Diagram B:

The refrigerant in this cycle will move in a clockwise pattern, following the blue arrows in Diagram B for refrigerant flow in heating mode. Beginning just after the expansion valve (D) the refrigerant starts off as a low temperature, low pressure liquid. Under this low pressure condition the refrigerant has a low boiling point. The refrigerant is pushed through the evaporator coil (A) where it then absorbs heat from the warm air that is passing over the coils. The heat absorbed by the air causes the refrigerant to boil and become a vapor. The refrigerant continues through the system toward the compressor (C), note the position of the reversing valve. The refrigerant is a low temperature, low pressure vapor.

The refrigerant enters the compressor where it is pressurized into a high temperature, high pressure vapor. The high pressure refrigerant has a high boiling point and can condense easier. As the refrigerant moves through the condenser coil (F) it expels heat to the air that is pushed though the fins on the coils by the fan (B). The passing air will absorb the heat causing the refrigerant to cool and condense into a liquid. The warmer air will be exhausted into the space. The high-pressure liquid refrigerant moves towards the outlet of the condenser, the expansion valve. The refrigerant will pass through the valve as a high temperature, high pressure liquid and it will come out as a low temperature, low pressure liquid and start the process over again.

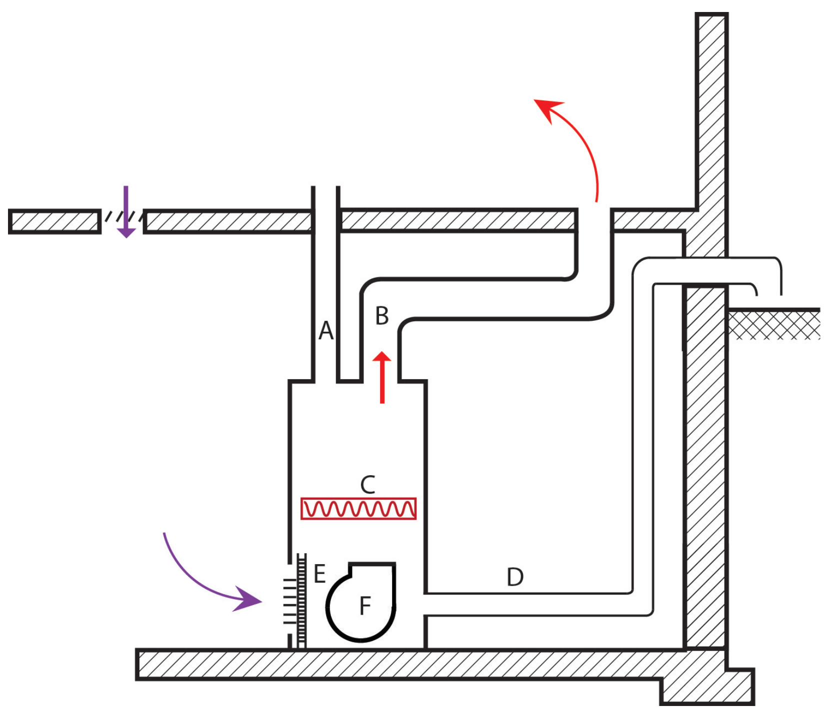
System Variations:

1. The setup and layout of a heat pump can vary depending on the design and manufacturer.
2. The discharge side of the unit may be located outside of the building while the supply side is located inside the building.
3. Depending on design the discharge side of the heat pump may be treated by water or outside air.
4. The overall unit may be built as a complete all-in-one box unit or as two separate units connected by refrigerant lines.

Forced Air Furnace

Components/Layout:

A: Vent
B: Supply Duct
C: Heat Exchange
D: Outside Air Intake
E: Filter
F: Blower Fan



Air Flow:

Air is drawn into the unit through the filter by the blower fan, at point E. The fan pushes air past the heat exchanger (C) which warms the air as it passes through. The resulting warmer air is sent through the supply duct (B) to the space. As the warm air is supplied to the space, the cooler air is pushed down and is drawn into the return and is reused by the system. A unit will typically operate until the space temperature is satisfied, at which time the furnace turns off. These units require a free flow of air to operate and for proper air flow should have open return air ducts and an unobstructed air path to help draw in air when operating.

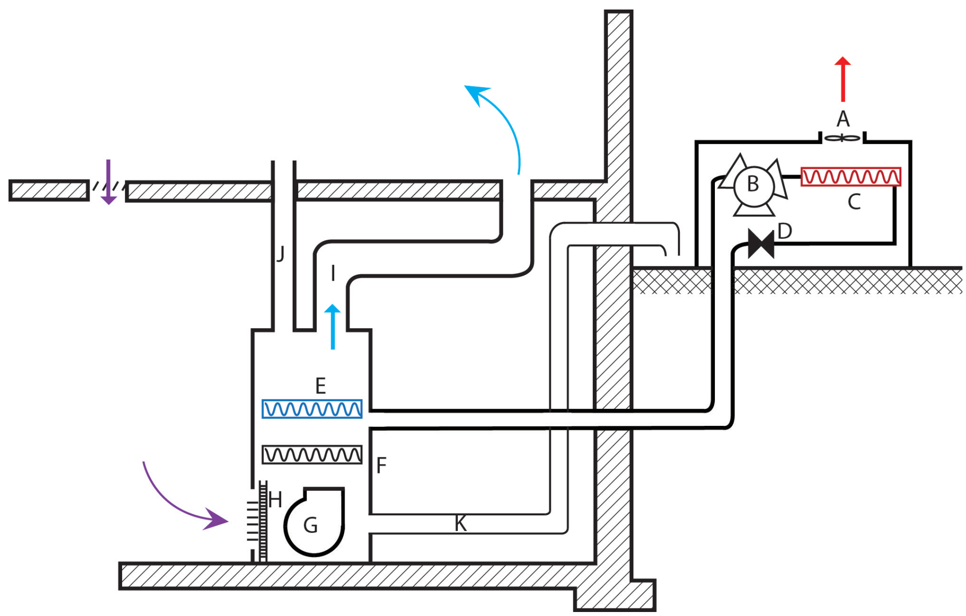
System Variations:

1. A system may utilize one of a number of means to heat the air (gas burner, electric coils, heat pump, or hydronic coils).
2. The return for a unit may be actual ductwork or may be return grates cut into the floors and walls to create circulation.
3. Humidification unit may be present after the heating coil depending on the design.

Forced Air Cooling

Components/Layout:

A: Exhaust Fan
B: Compressor
C: Condenser Coil
D: Expansion Valve
E: Evaporator Coil
F: Heating Coil
G: Blower Fan
H: Filter
I: Supply Duct
J: Vent
K: Outside Air Intake



Air Flow:

This unit utilizes the air circulation methods of a forced air furnace; however it is being used for cooling as well as heating. Air is drawn into the unit through the filter, (H), and is pulled through the blower (G). The blower pushes air past the heating coil or heat exchanger (F), but this coil will not operate when cooling. The air continues past to the evaporator coil or cooling coil (E), which cools the air as it passes through. The resulting air is sent through the supply duct (I) to the space. The systems main goal is to sensibly cool the passing air. Any dehumidification that may happen will be a byproduct of the process. The cooler air that exits the system may have lost some moisture in the cooling process but will have a higher relative humidity. The unit will typically operate until space temperature is satisfied at which time the unit turns off. These units require a free flow of air to operate and must have open return air ducts or an unobstructed air path to help draw in air when operating.

Refrigerant/Heating Supply:

The system works like a basic air conditioner with a few changes in positioning. The expansion valve (D), compressor (B) and condenser (C) are located outside of the building, while the evaporator coil (E) is inside the furnace. The refrigerant must travel through long lengths of tubing from inside to outside

Beginning just after the expansion valve refrigerant starts off as a low temperature, low pressure liquid. Under this low pressure condition the refrigerant has a low boiling point. The refrigerant is pushed through the evaporator coil where it absorbs heat from warm air that is passing over the coils. The heat absorbed from the warm air causes the refrigerant to boil and become a vapor. The refrigerant continues through the system toward the compressor. As it enters the compressor the refrigerant is now a low temperature, low pressure vapor.

The refrigerant enters the compressor where it is pressurized into a high temperature, high pressure vapor. The refrigerant is now under very high pressure and has a high boiling point. At these conditions, the refrigerant can condense easily. As the refrigerant moves through the condenser coil the fan inside the unit pushes air across the coils. The refrigerant will expel heat to the passing air as it is pushed though the fins by the fan. The passing air absorbs the heat, causing the refrigerant to cool and condense into a liquid. The high-pressure liquid moves towards the outlet of the condenser, the expansion valve. The refrigerant will enter the valve as a high temperature, high pressure liquid. The valve allows the pressure of the refrigerant to change and the refrigerant will exit the valve as a low temperature, low pressure liquid and start the process over again.

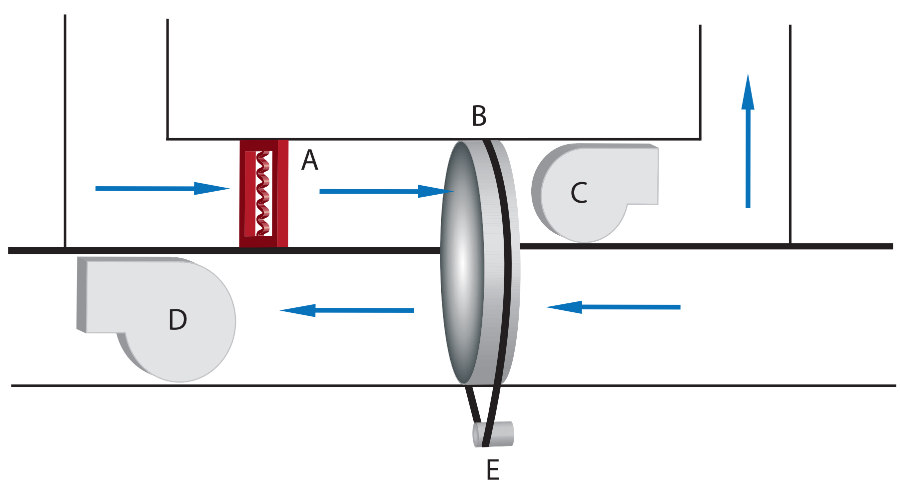
System Variations:

1. A return for the unit may be actual ductwork or may be return grates cut into the floors and walls to create circulation.

Desiccant Wheel

Components/Layout:

A: Heating Coil
B: Desiccant Wheel
C: Exhaust Fan
D: Supply Fan
E: Wheel Motor



Air Flow:

This system can exist as a stand-alone system or within an air handling unit. The desiccant wheel (B) is a spinning wheel that contains a desiccant material and is connected to a motor (E). The wheel spins inside two sets of ductwork, a large duct and a small duct. Inside the large duct, ¾ of the wheel is exposed. The smaller duct encloses ¼ of the wheel. Air that is to be dehumidified, process air, enters the large duct and is pulled across the desiccant wheel. The moisture in the air is absorbed into the desiccant. The air is then pulled into a fan (D) and pushed out of the unit. The process air leaving the unit has a much lower moisture content that when it entered the unit and is slightly warmer.

Back inside the unit the desiccant wheel turns delivering the moisture laden desiccant to the smaller ductwork. Here, outside air is used to reactivate the desiccant; this is referred to as regeneration air. The outside air is drawn into the system and is heated significantly by a heating coil (A) as it passes. This heated air has a greater ability to hold moisture and is pulled across the desiccant in the opposite direction of the process air. As the air crosses the desiccant it picks up moisture from the wheel and dries the desiccant. The regeneration air is then drawn into a fan (C) and exhausted out of the building as hot/humid air. The wheel continues to turn and the reactivated desiccant is ready to treat the space again.

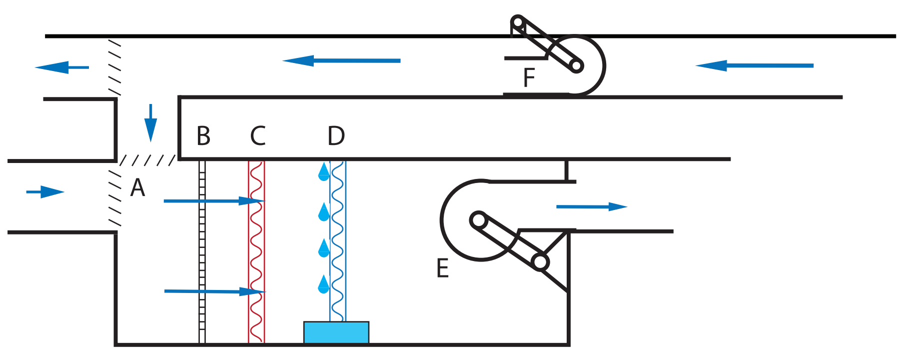
System Variations:

1. The arrangement of the ductwork on the desiccant wheel may vary from unit to unit.
2. A desiccant wheel may pretreat air before it enters an air handler or condition air that is passing through an air handler, depending on design.
3. A desiccant unit does not need to be connected to an air handler, it can be stand-alone.

Evaporative Cooling System

Components/Layout:

A: Dampers
B: Filters
C: Heating Coil
D: Evaporative Media
E: Supply Fan
F: Return Fan



Air Flow:

This type of unit may be common in areas like Arizona and Nevada, where moisture removal from the air is not a concern and where the moisture added to the air from this system helps to improve the low dew point. Starting at the outside air intake, air enters the outside air duct and is mixed with return air from the space just before the filters (B). The mixed air is pulled through a set of filters where impurities are removed. The air then passes over a set of heating coils (C) where the air is heated to the required temperature if necessary. The air then passes through the evaporative media (D). This media is a pad utilizing a honeycomb design that is saturated with cool water. As the air passes over the media, water from the pad is evaporated into the air. This process removes energy from the air resulting in a lower/cooler temperature, while at the same time adding moisture to the passing air, increasing the dew point. Next, the air is pulled into the supply fan (E), which will push the air through the supply ductwork, through the diffusers and into the space. The return fan (F) will then pull in air from the space and push it through the return ductwork. Air is either exhausted or returned to the unit to be mixed with outside air and start the cycle all over again.

Refrigerant/Coolant Cycle:

The heating coils are fed from a heat source such as a boiler or electricity. The heat from these coils is transferred to the air passing over it.

The evaporative media is a pad made of a cellulose material that utilizes a honeycomb design. A supply system adds water by pouring or dripping water onto the face of the media. This water cascades down the media and what is not absorbed or evaporated to the air will collect in a special pool. Water from the pool is pumped back up to the top of the media and reused. The pool is designed with a float to prevent overflow and a water supply line will replace any lost water if the pool gets too low.

System Variations:

1. A system may have multiple sets of filters to remove different levels of impurities.
2. A heating coil may not be present in every unit.
3. A heating coil may be farther down the line in the ductwork in what is called a reheat. As a reheat the coil will heat the air for a specific space just before it is discharged from the ducts.
4. A return fan may not be present in every unit. If the supply fan creates enough of a draw, it pulls the air back through the space.

Hydronic Radiant Heat Systems
(ex: baseboard, radiant floors, radiators, etc.)

Components/Layout:

A: Relief Valve

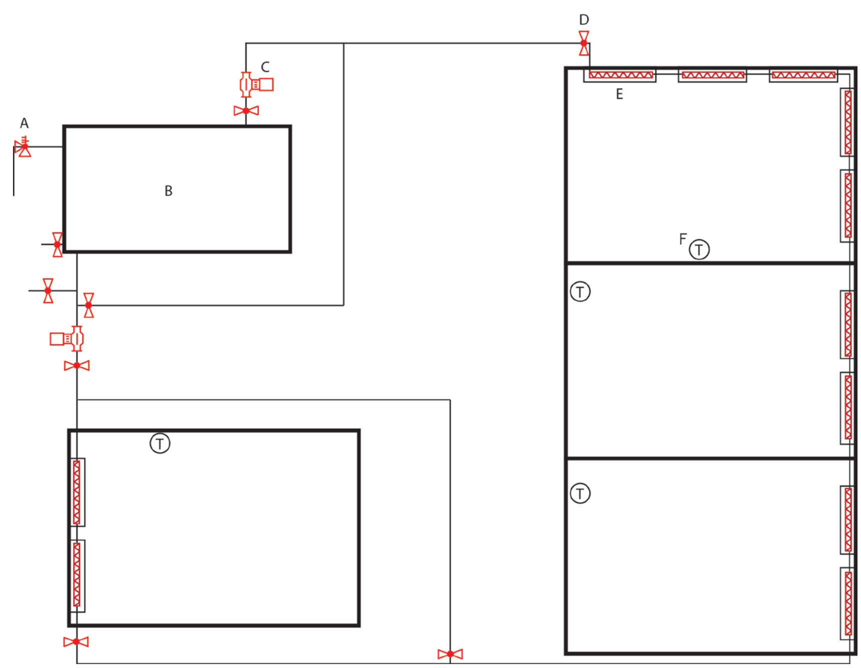
B: Boiler

C: Pump

D: Valve

E: Radiator

F: Thermostat



Air Flow:

Radiators are heat emitting units that transfer a portion of their heat through radiation and a portion of their heat by convection. Air that is in contact with the radiators will absorb heat through convection, while objects near the radiators will absorb heat through radiation. Frames or casings around the inner coils will help direct the heat movement away from the radiators. Blocking or covering these radiators with furniture or window coverings will hinder their efficiency.

Hot Water Radiant System

This system starts off with water heated at a main source (boiler, hot water system, etc.). This water is turned into either steam (220°F) or hot water (170°F). Some systems may even use high temperature water (350°-450°F) or medium temperature water (250° - 350°F). The high and medium temperature systems operate under high pressure to avoid the water flashing to steam.

In a hot water system, the water will be pumped from the boiler (B) through the supply lines to the radiators (E). The water enters the radiators on one side traveling through a fin covered line where the heat from the water is transferred to air from the space as the air passes through the fins. As the water passes through the radiators heat from the water is lost. The water exiting the radiators is cooler than the water that entered the radiators. Upon leaving the radiator the cooler water will either connect in a series to other radiators or return to the boiler, depending on the design of the system.

If the radiators are connected in a series the water will flow from outlet to inlet of the connected radiators until the end of the loop. At the end of the loop they will connect back to the main line and return to the boiler.

Some systems may have multiple loops that will come off a main line, while in other systems there may be a dedicated supply line and a dedicated return line. Radiators that use the dedicated line design will have their own feed from the supply and to the return. All of the loops will connect back to the main line and will eventually return to the boiler. Hot water boilers do not typically need to be installed at a specific level compared to their radiators.

System Variations:

1. A system may have individual valves on each radiator, room, floor, or loop to isolate an area depending on design.
2. Depending on the length of the loop there may be only one supply pump.
3. A system may be zoned to treat each room, area, or floor individually.
4. A system may be stand-alone or a complement to an air handling system.

Steam Radiant System

In this system water is turned into steam which is released from the boiler and travels up the pipes to the radiators. The radiators are connected individually off of the main line, with a high line feeding the radiators steam and a low line out the other side to collect the water that has condensed. The steam and water will exit the radiators to a second line that is installed at a slope so that the condensed water may drain to a return pipe that serves as a wet supply for the boiler. Multiple radiator drains may be connected to one main line, but the radiators will not be connected in series as a hot water system would be. In a steam boiler water system, the boiler may be located at least a floor below the radiators so that the steam can rise to the radiators and the water can run downhill back to the boiler.

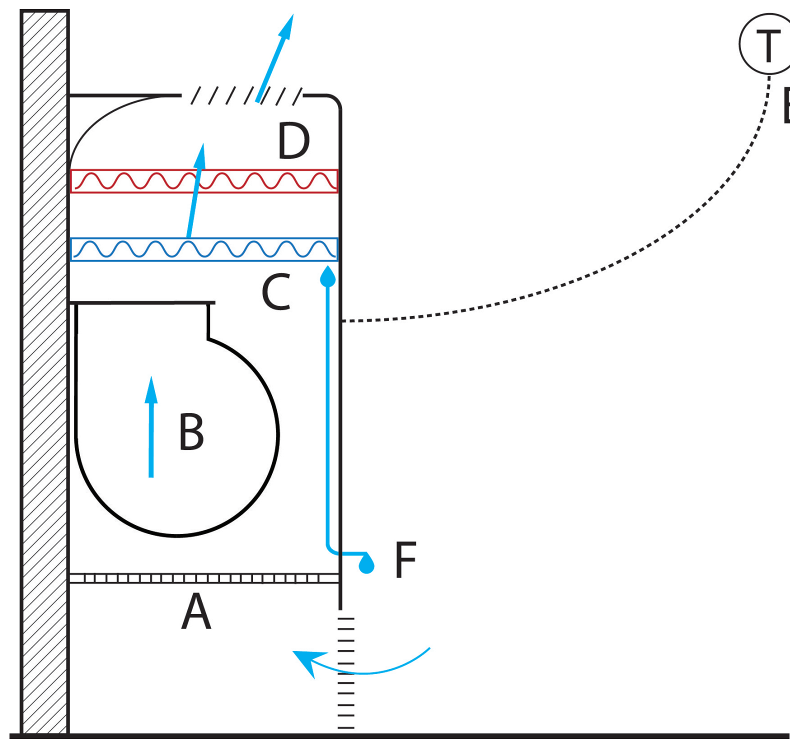
System Variations:

1. The system may have individual valves on each radiator, room, floor, or loop to isolate an area depending on design.
2. The system may be zoned to treat each room, area, or floor individually.
3. The system may be a stand-alone or a complement to another air handling system.

Wall Mounted Unit

Components/Layout:

A: Filter
B: Fan
C: Coiling Coil
D: Heating Coil
E: Thermostat
F: Condensate Drain



Air Flow:

Air enters the system through dampers at the base of the unit. As the air is drawn in it is treated by a filter (A) to screen out any contaminants. This air is pushed by the fan (B) into the heating (D) and cooling coils (C) where the air is treated if necessary. The conditioned air is then pushed out the top of the unit into the space.

Refrigerant/Heating Supply:

The cooling coils are fed from a source of cooling (chillers, cooling tower, DX unit). The refrigerant enters the coils which absorb heat and remove moisture from the air in the ducts. The refrigerant returns to its cooling source to desorb the heat that it has taken in.

The heating coils are fed from a heat source (boiler, electricity). The heat from these coils is transferred to the air passing through it.

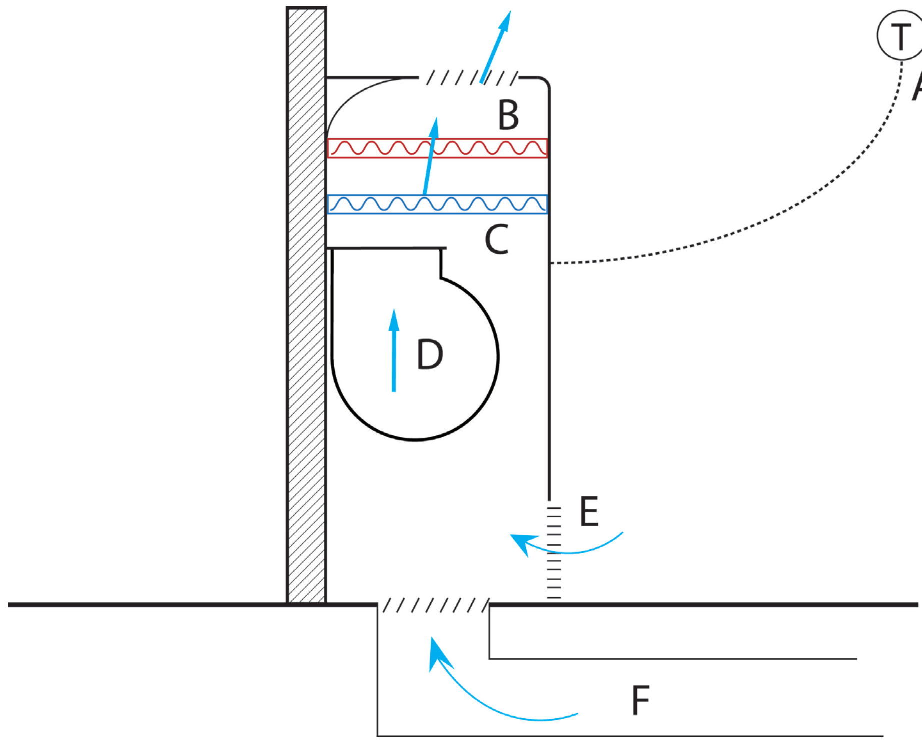
System Variations:

1. Cooling coil may not be present on all units.
2. Heating coil may not be present on all units.
3. Thermostat may be mounted on a panel on the unit or may be found elsewhere in the room depending on design.
4. Unit may be mounted at different heights depending on design.
5. Unit may be in addition to a central AHU.

Induction Heating Unit

Components/Layout:

A: Thermostat
B: Heating Coil
C: Cooling Coil
D: Fan
E: Return Air
F: Pre-treated Air



Air Flow:

These units are similar to the standard wall mounted unit and are typically what many hotel rooms use. Pretreated air is supplied to the unit from a main air handling system (F). The air is mixed with other air from the space that is pulled in through dampers (E) at the bottom of the unit. This mixed air is pushed through the fan (D) into the heating (B) and cooling coils (C) where the air is treated if necessary. The typical function of the cooling coil is to sensibly cool the passing air. Little to no dehumidification is performed by this unit. The conditioned air is then pushed out the top of the unit into the space. These units typically do not have any form of humidification installed on them.

Refrigerant/Heating Supply:

The cooling coils are fed from a source of cooling (chillers, cooling tower, DX unit). The refrigerant enters the coils which absorb heat and remove moisture from the passing air. The refrigerant returns to its cooling source to desorb the heat that it has taken in.

The heating coils are fed from a heat source (boiler, electricity). The heat from these coils is transferred to the air passing through it.

System Variations:

1. The arrangement of the cooling coil and heating coil may vary from unit to unit.
2. A cooling coil may not be present in every unit.
3. A heating coil may not be present in every unit.
4. A unit may not always be oriented vertically.
5. A unit may be installed on a wall or ceiling.
6. A unit may have a set of filters installed before the fan.

Air Dryer

Components/Layout:

A: Filter

B: Evaporator Coil Extension

C: Evaporator Coil

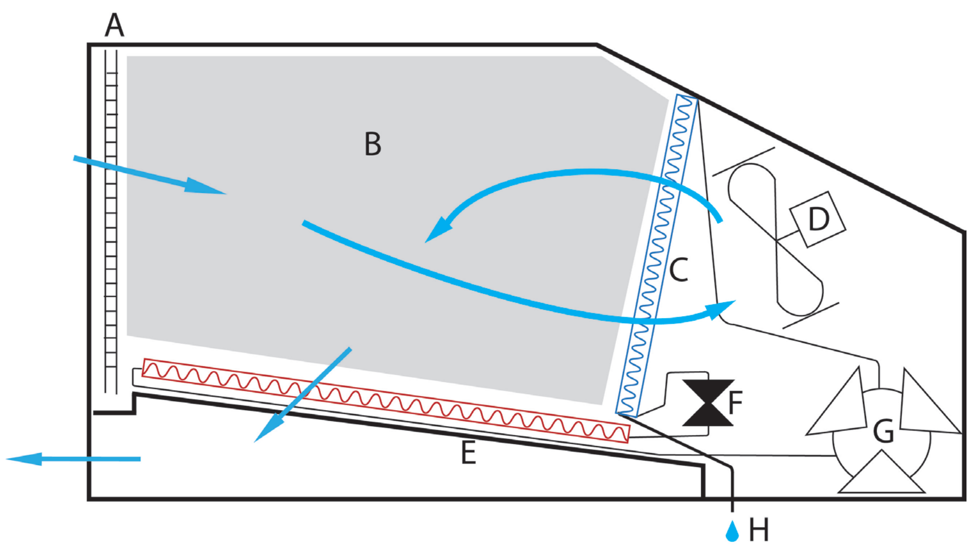
D: Fan

E: Condenser Coil

F: Expansion Valve

G: Compressor

H: Condensate Drain



Air Flow:

Air is brought into the unit through the filter (A). The air enters a large evaporator coil (B), here it is cooled and the temperature of the coil is very low. If the passing air has a higher dew point than the coil temperature, moisture in the air will condense and drop onto a condensation tray. The condensation tray will allow the water to drain out of the unit. The cool air is brought to the back of the unit then pushed downward where it will pass through a condenser coil (E) that is used to heat the air before ejecting it out the rear of the unit.

Refrigerant/Coolant Cycle:

The system works just like a basic air conditioner. Beginning just after the expansion valve (F) the refrigerant starts off as a low temperature, low pressure liquid. Under this low pressure condition the refrigerant has a low boiling point. The refrigerant is pushed through the evaporator coil (C) where it absorbs heat from the warm air that is passing over the coils. The heat absorbed by the warm air causes the refrigerant to boil and become a vapor. The refrigerant continues through the system toward the compressor (G). As it enters the compressor the refrigerant is now a low temperature, low pressure vapor.

The refrigerant enters the compressor where it is pressurized into a high temperature, high pressure vapor. The refrigerant is now under very high pressure and has a high boiling point. At these conditions, the refrigerant can condense easily. As the refrigerant moves through the condenser coil (E) the fan inside the unit is pushing air across the coils. The refrigerant will expel heat to the passing air as it is pushed though the fins by the fan. The passing air will absorb the heat, causing the refrigerant to cool and condense into a liquid. The high-pressure liquid moves towards the outlet of the condenser, the expansion valve. The refrigerant will enter the valve as a high temperature, high pressure liquid. The valve will allow the pressure of the refrigerant to change and the refrigerant will exit the valve as a low temperature, low pressure liquid and start the process over again.

System Variations:

1. This system can take a variety of shapes and sizes.

Mechanical System Acronyms

AC – Air Conditioning

ACH – Air Changes per Hour

ACU – Air Conditioning Unit

AHU – Air Handling Unit

ASHRAE – American Society of Heating Refrigeration and Air Conditioning Engineers

BAS – Building Automated System

BMS – Building Management System

BTU – British Thermal Unit

BTUh – British Thermal Unit per hour

C – Celsius

CAV – Constant Air Volume

CC – Cooling Coil

CFC - Chlorofluorocarbon

CFM – Cubic Feet per Minute

CHW – Chilled Water

CHWP – Chilled Water Pump

CHWR – Chilled Water Return

CHWS – Chilled Water Supply

DB – Dry Bulb

DDC – Direct Digital Control

DP – Dew Point

DX – Direct Expansion

EA – Exhaust Air

EAT – Entering Air Temperature

EER – Energy Efficiency Ratio

EF – Exhaust Fan

EMS – Energy Management System

EWT – Entering Water Temperature

F – Fahrenheit

FCU – Fan Coil Unit

FLA – Full Load Amps

FPM – Feet per Minute

FPS – Feet per Second

GPM – Gallon per Minute

HC – Heating Coil

HEPA – High-Efficiency Particulate Arrestor

HP – Heat Pump or Horse Power

HPS – High Pressure Steam

HW – Hot Water

HWP – Hot Water Pump

HWR – Hot Water Return

HWS – Hot Water Supply

HVAC – Heating, Ventilation and Air Conditioning

Hz – Hertz

IR – Infrared

kW – Kilowatt

KWH – Kilowatt-hour

LAT – Leaving Air Temperature

LEED – Leadership in Energy and Environmental Design

LL – Low Limit

LP – Low Pressure

LPS – Low Pressure Steam

LWT – Leaving Water Temperature

LWB – Leaving Wet Bulb

MA – Mixed Air

MAT – Mixed Air Temperature

MUA – Make Up Air

NC – Normally Closed

NO – Normally Open

OA, OSA – Outside Air

OAI – Outside Air Intake

OAT – Outside Air Temp

PM – Preventative Maintenance

PH – Preheat

PSI – Pounds per Square Inch

RA – Return Air

RF – Return Fan

RH – Relative Humidity

RPM – Revolutions per Minute

RTU – Roof Top Unit

SA – Supply Air

SD – Smoke Detector

SF – Supply Fan

T – Temperature or Thermostat

V – Volts

VAV – Variable Air Volume

VD – Volume Damper

VFD – Variable Frequency Drive

VSD – Variable Speed Drive

W – Watts

WB – Wet Bulb

ZD – Zone Damper

METHODOLOGY:
DOCUMENTATION

This initial step for the environmental management team not only provides the information needed to proceed, but is also an important team-building exercise. The discovery and sharing of information, commonly used terminology, job responsibilities and background knowledge can create a better working relationship between team members and a strong sense of shared responsibility for long-term collection preservation.

Documentation worksheets are provided in this section and broken into three categories:

- Documentation of the building
- Documentation of mechanical systems
- Documentation of storage and exhibition spaces

The information that is collected for these documents will help paint a picture of the facility and the air handling system and determine the parameters for any testing that will be employed. The collected information will shed light on building occupancy, use, air distribution, what the system can do and what temperature and RH levels the collection can withstand, among other information. The team will use this information to help formulate a plan for what strategies can be employed and how to employ them. The more data that is available the easier the strategies may be to plan.

It is not necessary to have all the information or documentation that is suggested. Some institutions may have little to none of this information, while other institutions will have most of the documentation readily available. Not having all of the recommended documents should not end the project. If the documentation is missing, some of it can be found by asking the right staff members or determined by an examination of the building or system. For example, not knowing the design dew point control of a system can be substituted by installing dataloggers and tracking and evaluating dew point conditions in the system and spaces. If mechanical drawings are missing, cartooning can replace a section diagram, and zone maps can be created by following ductwork and drawing it in on a floor plan of the facility.

Recreating or creating some of this documentation should be an important consideration whether for the project or for institutional knowledge. It is very useful in a facility to know the system operation or what air handling unit serves what area of the building. Learning the facility and its operation will benefit the team as a whole. There is a good chance that some of the documentation may not have ever existed for a facility. In this case the team should build what they can, be aware of what they might be missing, and proceed with data gathering, which may help fill in some of the gaps. Again, not having all of this documentation should not immediately terminate the process.

The worksheets that follow include lists of certain information and documentation that may prove useful in the optimization and sustainable preservation process; however, these are by no means all-inclusive. Institutions may find additional documentation or material beyond these lists that apply to the building, system, or preservation environment – take advantage of whatever information you can find.

Documentation Meetings

Pre-meeting Process

- Each team member gathers all available and relevant documentation from their area of responsibility (see Documentation Worksheets).
- Each team member prepares a short-description of the following, according to their responsibilities and perspectives:
    - Their goals for the project
    - Current advantages (things that are going right)
    - Current shortcomings (things that need improvement)
- Conduct a team walk-through of the collections spaces and mechanical systems to be examined during the process.
- Create a main project collection point, (binder, folder on a shared file server) where all information and files pertaining to the project can be stored and accessible to the team. Note that this resource should consist of copies of the original documentation – all original copies should remain with the office where they originated.

Initial Documentation Meeting Activities:

- Focused group, often 3 to 5 individuals
- Statement of current/primary concerns regarding:
    - Preservation
    - Energy use
    - Mechanical system capabilities
- Establish documentation goals and plans for the use of this information:
    - Identify which spaces hold collection materials for storage, exhibition, etc. (use floor plans to identify each).
    - Identify which mechanical systems serve which collections spaces (use zone maps and mechanical drawings to confirm). Note instances of:
        - One system serving one space
        - Many systems serving one space
        - One system serving many spaces (including spaces that are not collections)
    - Identify non-collections spaces that may also be served by the same air-handling units.
- Identify and review your ability to measure the actual storage climate over time in each area where

significant collections are housed (dataloggers, data analysis software).

- Identify your ability to document and verify mechanical system operation and current environmental data gathering capability of mechanical systems (BMS trending software, data logging).
- Identify the need for any additional documentation from each area:
    - Additional or improved data logging – number of dataloggers needed and locations where the dataloggers will be placed
    - Upgraded data analysis software
    - New or improved trending software
    - Other documents to be located or created

Follow-up Documentation Meeting Activities

- Begin creating zone maps and mechanical cartoons if needed; these can also be worked on and completed during the Data Gathering phase.
- Gather any documentation or information identified as missing during the initial Documentation meeting.
- Continue adding documentation to the team binder/file share, including lists of missing documentation, project and equipment needs, etc.
- Full documentation and review among the team may take 2-3 meetings, depending on the availability and quantity of material.

Collection Space Documentation to Gather:

- Type of collection – information about material types, risks, (including risk assessment if available), existing degradation
- History of concerns (leaks, insects, mold, dust, etc.)
- Housing – storage layout equipment and housing
- Space use information – storage/exhibition, etc., hours of occupancy, lighting (type, quantity, method of control)
- Collected environmental data
    - Number, location, and type of dataloggers in use
    - Date range of available data
    - Temperature, relative humidity, and dew point graphs (digital or analog?)
- Documentation of the mechanical system(s) serving the space

- Locations of supply air diffusers and return air intakes
    - Positive vs. Negative Pressurization – test at doors and windows with a tissue or light piece of paper. If the tissue blows into the room, the room is negative. If it pushes against the door or window, the room is positive.

Collection Space Documentation Worksheet

Building: ____________ Floor: ____________

Room Number/Name: ____________

Primary Use: ☐ Storage ☐ Exhibition ☐ Accessioning/ Cataloging

☐ Other ____________

Storage Furniture:

☐ Open shelving ☐ Closed cabinets ☐ Compact shelving

☐ Rolling racks/ Wall mounted racks ☐ Rolled textiles

☐ Other ____________

Are materials stored in boxes and/or covered in some manner?

____

Environmental Documentation:

☐ Collection risk assessment

☐ Preservation requirements (Optimal conditions)

☐ Previous conditions

Notes: ____________

____

____

Dataloggers in the space:

Datalogger Type	Location	Serial #	Comments

Mechanical System Serving the Space:

AHU #(s): ____________________

Sketch of space: (Mark locations of thermostats, other sensors, supply and return vents)

Is the space positively or negatively pressurized?

Number and Type of Stand-alone Conditioning Units Used in the Space:

☐ Humidifier ☐ Dehumidifier ☐ Fan

☐ Other: ____________________

Lighting:

☐ Type: ☐ Hours of use:

Structural Information:

Number of exterior walls: Insulated? Vapor barrier? ____________________

Number of exterior doors: Sealed? ____________________

Number of windows: Protection from natural light? ____________________

Number of interior doors: ____________________

Use of surrounding spaces: ____________________

Sources of water (pipes, sinks, nearby bathrooms, utility closets, etc.): ____________________

Occupation of Space:

Human occupation - frequency of work or other activities in the area: ____________________

Types of ongoing activities: ____________________

Hours of occupation: ____________________

Office or other equipment use: ____________________

Concerns (note, location, date, etc.):

Leaks: ____________________

Pest incursions: ____________________

Mold: ____________________

Dust: ____________________

Building Documentation to Gather:

Don't expect to find everything on the list – gather what is available to you.

- Current floor plans (simple view – can often use copies that are required for building safety)
- Original floor plans
- As-built original architectural drawings
  - Architectural series
  - Information on wall construction, insulation, and vapor barrier
- Current architectural drawings (any updated drawings of the spaces in question)
- Building envelope studies
- Air-handling zone maps
- Occupancy (public and staff hours)
- Energy usage data (cost/usage compared to goals)
- Current plans for future building updates
- Note and mark all door and window locations on the building map
- Optional:
  - Fire protection drawings and information
  - Plumbing drawings showing location of pressurized water lines and floor drains
- Other (on as needed basis):
  - ________________________________
  - ________________________________
  - ________________________________

Notes: ____

____

____

____

HVAC Documentation to Gather:

Don't expect to find everything on the list – gather what is available to you.

- As-built original mechanical series (should include heating, air conditioning, and ventilation information)
- As-built original electrical series
- Design schedule for the mechanical system
- Current mechanical series (any updated drawings to the systems in question)
- Current electrical series
- Original sequence of operation, including:
    - System set points
    - Operating schedule
- Current sequence of operation
- Air-balancing studies
- Plans for future mechanical updates
- Other (on as needed basis):
    - ____________________________________
    - ____________________________________
    - ____________________________________

Notes:

How to Fill Out the HVAC Worksheet

What you will need

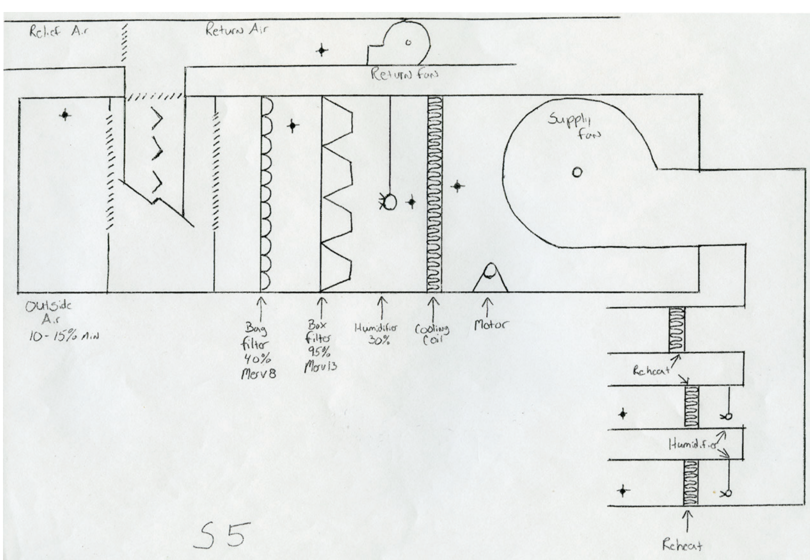
- Access to your mechanical system
- Assistance from your facilities or maintenance staff
- A cartoon sketch of your AHU
- Blueprints
    - Preferably the M series of prints. This is the series of prints that details the HVAC system layout and design. In the M series you will need to locate the schedule for the HVAC system and the prints that indicate the AHU location and duct layout.

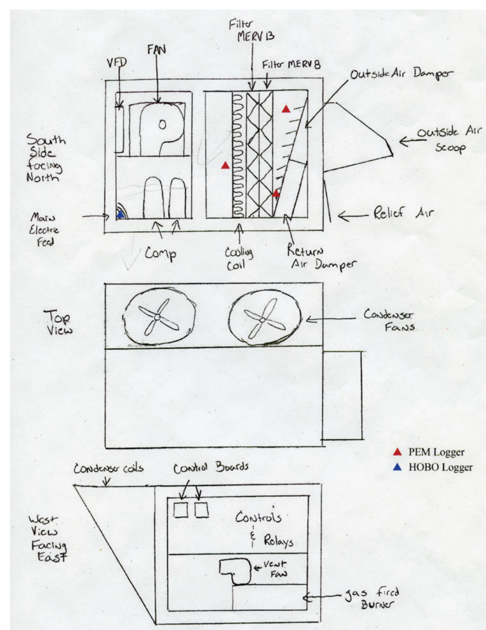
Mechanical System Cartoon

Your cartoon does not have to be perfect. It is a reference, and provides two major advantages:

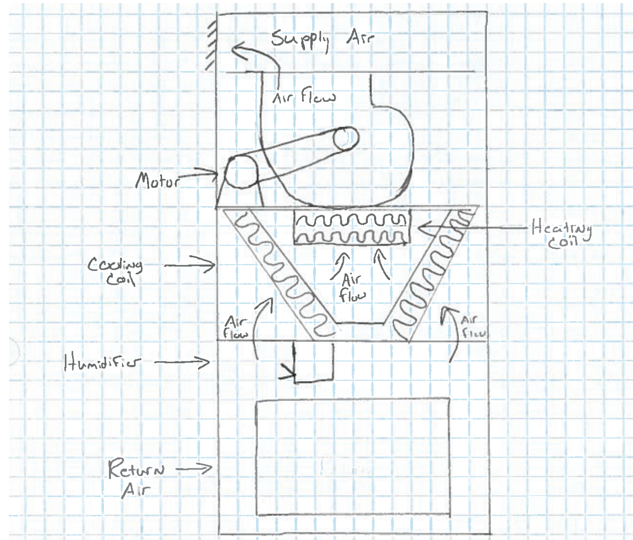
- It helps you understand the layout and air flow inside your unit. This will help you understand what work is done to the air and where.
- It also provides a reference for the unit that you can refer to at any time. If a component were to fail in the unit, the cartoon can help you understand exactly how that will effect your environment.

Below are a few examples of what your cartoon may look like:





Below is a mechanical system (left) and a cartoon for the system (right):



HVAC Worksheet

Begin by filling out the mechanical system notes section of the form.

Location: The room or area of the building that the system is located in.

Type: Is the unit a roof top unit, standalone, dual duct, etc.

Manufacturer: Who built this unit?

Model & Serial number: May be available by locating a name plate on a unit. However, not all units are labeled with a model and serial number.

BMS system: Is this unit on a BMS system?

Locating the Prints

Drawing Number System

- There is a specific number system designed for organizing blueprints
- This number can be found in the title block of the print
- This will help you locate a print for a specific area faster
- A cover page for the blueprints will sometimes break down what drawings are included and how many pages there should be for each

A = Architectural

C = Civil

E = Electrical

F = Fire Protection

I = Interior Furnishings

L = Landscape

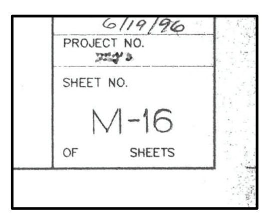
M = Mechanical

P = Plumbing

Q = Equipment

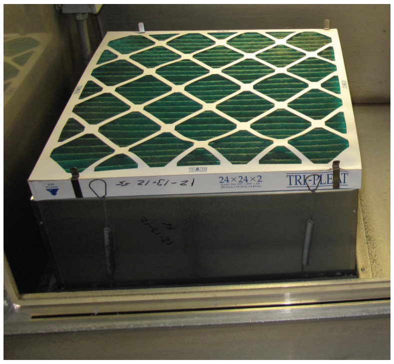
S = Structural

T = Telecommunications

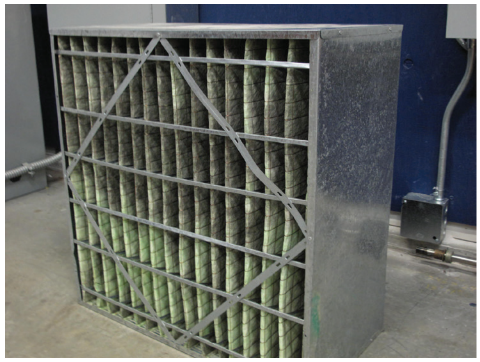


Filter Capacity

The filter capability section is best filled out by visiting the unit and seeing first hand what filters are being used. Below are sample images of some filters you may find in a unit. Most units will likely have only one or two of these filters.



Pleated or Pre-filters



Box Filters

Charcoal Filters

Gas Phase

Bag Filters

The MERV rating can be found on the side or label of most filters

Standard Air Filters

PRE Filter (G Class)	< 65%	MERV 1	G1	Am < 65%	Particle bigger than 10.0 μm • Pollen • Spanish moss • Dust mites • Sanding dust • Spray paint dust	• Minimal filtration • Residential • Window A/C units
	65-70%	MERV 2	G2	65% ≤ Am < 80%		
	70-75%	MERV 3				
	75-80%	MERV 4				
	80-85%	MERV 5	G3	80% ≤ Am < 90%	Particle size within 3.0 μm-10.0 μm • Mold • Spores • Hair spray • Cement dust • Snuff • Powdered milk	• Commercial buildings • Better residential • Industrial workplace • Paint booth inlet
	85-90%	MERV 6				
	25-30%	MERV 7	G4	90% ≤ Am		
	30-35%	MERV 8				

Am: Average arrestance efficiency for coarse filters   Em: Average efficiency for fine filters

High Efficiency Air Filters

HEPA Filter (H Class)	≥ 95% at 0.3 μm	n/a	H10	≥ 85% at MPPS	Particle bigger than 0.3 μm • Virus (unattached) • Carbon dust • Sea salt • All combustion smoke • Radon progeny	All types of cleanrooms
	≥ 98% at 0.3 μm		H11	≥ 95% at MPPS		
	≥ 99.97% at 0.3 μm	TYPE A				
	≥ 99.99% at 0.3 μm	TYPE C	H12	≥ 99.5% at MPPS		
	≥ 99.995% at 0.3 μm		H13	≥ 99.95% at MPPS		
	≥ 99.999% at 0.3 μm	TYPE D	H14	≥ 99.995% at MPPS		
ULPA Filter (U Class)	≥ 99.9995% at 0.12 μm	TYPE F	U15	≥ 99.9995% at MPPS	Particle size bigger than 0.12 μm	Super cleanroom
	≥ 99.99995% at 0.12 μm		U16	≥ 99.99995% at MPPS		
	≥ 99.999995% at 0.12 μm		U17	≥ 99.999995% at MPPS		

MPPS: Most penetrating particle size

Blueprints

- Be sure to verify with your facilities or maintenance department the accuracy of your prints.
- Older prints may have out-of-date information as components are repaired, replaced or upgraded over time.
- "As-built" prints are the better prints to have. Any final changes to design or layout during construction should be included in the as-built prints.

No Prints

- If no prints are available for the equipment, specifications for the equipment may be found by searching online using the manufacturer and model number as the query.
- For some smaller equipment a user or installation manual is available that can provide the necessary information. If these are not available to you on-site, many can also be found online once you know the correct model and serial number.

Reading the AHU Schedule

- Not all schedules will look the same
- Not all prints will have all of the necessary information on them
  - Some prints will not have the exiting wet and dry bulb conditions
  - Some schedules may not have fan speeds
- Using the prints you have, try to get as much information as possible to complete the HVAC forms.

GENERAL				
MARK	SEE DWG. NO.	SERVICE	ARRG	TYPE
ACU-1	2	1ST, 2ND & 3RD FLR'S	HORZ.	BLOW THRU
ACU-2	2	1ST 2ND & 3RD FLR'S	HORZ.	BLOW THRU
ACU-3	9	4TH & 5TH FLR'S	HORZ.	BLOW THRU
ACU-4	9	6TH & 7TH FLR'S	HORZ.	BLOW THRU

The highlighted section of the schedule contains the unit name or number.

Locate the AHU that will be used for the study.

Throughout the remainder of these instructions we will use ACU -1.

AIR HANDLING UNITS

GENERAL				FAN DATA										
MARK	SEE DWG. NO.	SERVICE	ARRG	TYPE	ARRG	CAP. C.F.M.	OUTLET VEL F.P.M.	STATIC PRESSURE EXT	STATIC PRESSURE TOT	WHEEL NO	WHEEL DIA	WHEEL RPM	WHEEL DRIVE	MOTOR H.P.
ACU-1	2	1ST, 2ND & 3RD FLR'S	HORZ.	BLOW THRU	DUAL DUCT	42690	—	—	8.0	1	44 1/2	1350	BELT	100
ACU-2	2	1ST 2ND & 3RD FLR'S	HORZ.	BLOW THRU	DUAL DUCT	43620	—	—	8.0	1	44 1/2	1350	BELT	100
ACU-3	9	4TH & 5TH FLR'S	HORZ.	BLOW THRU	DUAL DUCT	29125	—	—	8.0	1	33	1400	BELT	75
ACU-4	9	6TH & 7TH FLR'S	HORZ.	BLOW THRU	MULTI ZONE	22205	—	—	2.0	2	27	860	BELT	15

	FILTER DATA										HEATING DATA											
MARK	TYPE ELEC	TYPE AUTO	MECHANICAL CLEANABLE H. VEL	MECHANICAL CLEANABLE L. VEL	MECHANICAL DISP	NO	SIZE	SIZE	SIZE	FACE VEL. FPM	MEDIUM STEAM PRESS PSIG	HOT WATER INLET °F	HOT WATER OUTLET °F	FRESH AIR MIN %	HEATING COIL NO	SP	FACE VEL FPM	ENT. AIR °F	LEA. AIR °F	STM. LB-HR	HEATING COIL CFM
ACU-1	—	—	—	—	YES	24	27	24	24	—	2	—	—	25	1		900	60	95	1340	34200
ACU-2	—	—	—	—	YES	24	27	24	24	—	2	—	—	25	1		920	60	95	1370	35000
ACU-3	—	—	—	—	YES	15	27	24	24	—	2	—	—	25	1		800	65.6	95	790	23400
ACU-4	—	—	—	—	YES	15	27	24	24	—	2	—	—	25	1		800	67.5	110	735	15400

	COOLING DATA															REMARKS
MARK	CHILLED WATER NO.	ENT. TEMP °F	LEA TEMP °F	GPM	PD-FT	FRESH AIR MIN. %	AIR FACE VEL. FPM	ENTERING D.B. °F	ENTERING W.B. °F	LEAVING D.B. °F	LEAVING W.B. °F	REFRIG. LOAD TOTAL M-BTU	SENS. M-BTU	TOTAL TON	COOLING COIL CFM	
ACU-1	1	45	55	368	—	25	550	82.3	67.7	54	52.2	1,840	1210	153	39300	
ACU-2	1	45	55	377	—	25	550	82.3	67.7	54	52.2	1,880	1220	157	40200	
ACU-3	1	45	55	226	—	25	500	80.2	65.8	53	51.4	1,122	772	94	26300	
ACU-4	1	45	55	135	—	25	600	79.8	65.1	57	55.2	671	546	56	22205	

Cooling Capacity

- Type of cooling: For this system chilled water is used. See
- Entering water temp: Will be 45°. See
- Leaving water temp: Will be 55°. See
- Designs:
    - Leaving WB: Will be 52.2°. See
    - Leaving DB: Will be 54°. See
    - To determine the DP a psychrometric chart or online psychrometric calculator can be used. The following website is one example: http://www.csgnetwork.com/dewptrelhumcalc.html
- Face and Bypass: This may be determined by examining the unit. While inspecting the unit is there an alternative path for the air to pass around the cooling coil?

COOLING DATA														
CHILLED WATER					FRESH AIR MIN. o/o	AIR					REFRIG. LOAD			COOLING COIL CFM
NO.	ENT. TEMP °F	LEA TEMP °F	GPM	PD. - FT		FACE VEL. FPM	ENTERING D.B. °F	ENTERING W.B. °F	LEAVING D.B. °F	LEAVING W.B. °F	TOTAL M-BTU	SENS. M-BTU	TOTAL TON	
1	45	55	368	—	25	550	82.3	67.7	54	52.2	1,840	1210	153	39300
1	45	55	377	—	25	550	82.3	67.7	54	52.2	1,880	1220	157	40200
1	45	55	226	—	25	500	80.2	65.8	53	51.4	1,122	772	94	26300
1	45	55	135	—	25	600	79.8	65.1	57	55.2	671	546	56	22205

Heating Capacity

- Type of heating: For this system steam heat is used. See
- Heater location: This may be determined by examining the unit. Note where the heating coil is located in the unit.
- Reheats: Note if there are reheats located downstream in the ductwork. These may also be indicated elsewhere in the mechanical schedule.
- Mixing boxes: Note if there are mixing boxes downstream in the ductwork.
- Terminal VAV reheat: Note if there are VAV reheats downstream in the ductwork.

ING UNITS												
	HEATING DATA											
CE EL. PM	MEDIUM			FRESH AIR MIN o/o	NO	SP	HEATING COIL					NO
	STEAM PRESS PSIG	HOT WATER INLET °F	HOT WATER OUTLET °F				FACE VEL FPM	ENT. AIR °F	LEA. AIR °F	STM. LB-HR	HEATING COIL CFM	
—	2	—	—	25	1		900	60	95	1340	34200	1
—	2	—	—	25	1		920	60	95	1370	35000	1
—	2	—	—	25	1		800	65.6	95	790	23400	1
—	2	—	—	25	1		800	67.5	110	735	15400	1

Humidifier Capacity

This information may be found on the schedule or may be found by examining the unit.

- Type of humidifier: This is the type of humidification used by the system.
- Humidifier location: Note where the humidifier is located in the system.

Desiccant Type

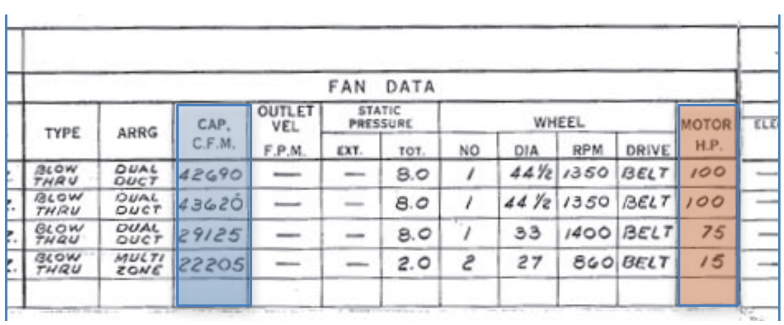
The desiccant would be an additional form of dehumidification that the system utilizes. This feature does not exist on all air handling systems. This information may be found on the schedule or may be found by examining the unit.

System Controls

- System Controls: Which method of control is used by the HVAC system.
- Brand: Which brand of control system is used.
- Interface: What type of interface is used between the system and brand.

Fans

- Most systems do not utilize all three types of fans. Many only use one or two fans.
- The information should be found in the schedule or on the prints. However, some information may require examining the unit.
- CFM: 42690 CFM. See
- Motor HP: 100. Can be found in schedule See or on the nameplate of the motor.
- Motor in airstream: Is the motor on the system located inside the unit or outside the unit? A motor located within the air stream can potentially add heat to the air.
- Hand Amp reading: Can be obtained by measuring one leg of power going into the VFD. **(NOTE: this should be performed by an experienced individual)**
- VFD: Is there a Variable Frequency Drive on the fan.



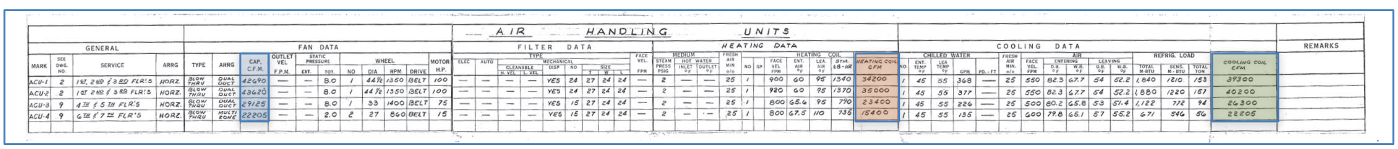
FAN DATA											
TYPE	ARRG	CAP. C.F.M.	OUTLET VEL F.P.M.	STATIC PRESSURE EXT.	STATIC PRESSURE TOT.	WHEEL NO	WHEEL DIA	WHEEL RPM	WHEEL DRIVE	MOTOR H.P.	ELE
BLOW THRU	DUAL DUCT	42690	—	—	8.0	1	44½	1350	BELT	100	—
BLOW THRU	DUAL DUCT	43620	—	—	8.0	1	44½	1350	BELT	100	—
BLOW THRU	DUAL DUCT	29125	—	—	8.0	1	33	1400	BELT	75	—
BLOW THRU	MULTI ZONE	22205	—	—	2.0	2	27	860	BELT	15	—

Condensing Unit and Settings

- Condensing Unit: What type of condensing unit is used for the system?
- Operational Settings: What are the daily temperature and humidity operational settings for the system? Are there any nightly setbacks used?
- Set points: Are seasonal set points used for winter and summer?
- Damper Type: This information may require examining the unit. Are the dampers for the system motorized or fixed? What is the position of the dampers when inspected?

Air Flow

- Total airflow: Total airflow for this system is 42690 CFM. See
- Airflow over coils
  - Heating Coil: 34200 CFM. See
  - Cooling Coil: 39300 CFM. See
- Outside Air: This would be the amount of air the system brings in from outside the building. This is not listed on this graphic.
- % Bypass: This would be the maximum amount of air that can bypass one of the coils. No bypass is available on this system.
- Economizer: This would be the amount of air the system was designed to use in economizer mode. No economizer mode is available on this system.



AIR HANDLING UNITS

GENERAL: MARK	SEE DWG. NO.	SERVICE	ARRG	FAN DATA: TYPE	ARRG	CAP. C.F.M.	OUTLET VEL F.P.M.	STATIC PRESSURE: EXT.	TOT.	WHEEL: NO	DIA	RPM	DRIVE	MOTOR H.P.
ACU-1	2	1ST, 2ND & 3RD FLR'S	HORZ.	BLOW THRU	DUAL DUCT	42690	—	—	8.0	1	44½	1350	BELT	100
ACU-2	2	1ST 2ND & 3RD FLR'S	HORZ.	BLOW THRU	DUAL DUCT	43620	—	—	8.0	1	44½	1350	BELT	100
ACU-3	9	4TH & 5TH FLR'S	HORZ.	BLOW THRU	DUAL DUCT	29125	—	—	8.0	1	33	1400	BELT	75
ACU-4	9	6TH & 7TH FLR'S	HORZ.	BLOW THRU	MULTI ZONE	22205	—	—	2.0	2	27	860	BELT	15

MARK	FILTER DATA: TYPE: ELEC	AUTO	MECHANICAL: CLEANABLE H. VEL	CLEANABLE L. VEL	DISP	NO	SIZE T	SIZE W	SIZE L	FACE VEL. FPM	HEATING DATA: MEDIUM: STEAM PRESS PSIG	HOT WATER INLET °F	HOT WATER OUTLET °F	FRESH AIR MIN %	HEATING COIL: NO	SP	FACE VEL FPM	ENT. AIR °F	LEA. AIR °F	STM. LB-HR	HEATING COIL CFM
ACU-1	—	—	—	—	YES	24	27	24	24	—	2	—	—	25	1		900	60	95	1340	34200
ACU-2	—	—	—	—	YES	24	27	24	24	—	2	—	—	25	1		920	60	95	1370	35000
ACU-3	—	—	—	—	YES	15	27	24	24	—	2	—	—	25	1		800	65.6	95	790	23400
ACU-4	—	—	—	—	YES	15	27	24	24	—	2	—	—	25	1		800	67.5	110	735	15400

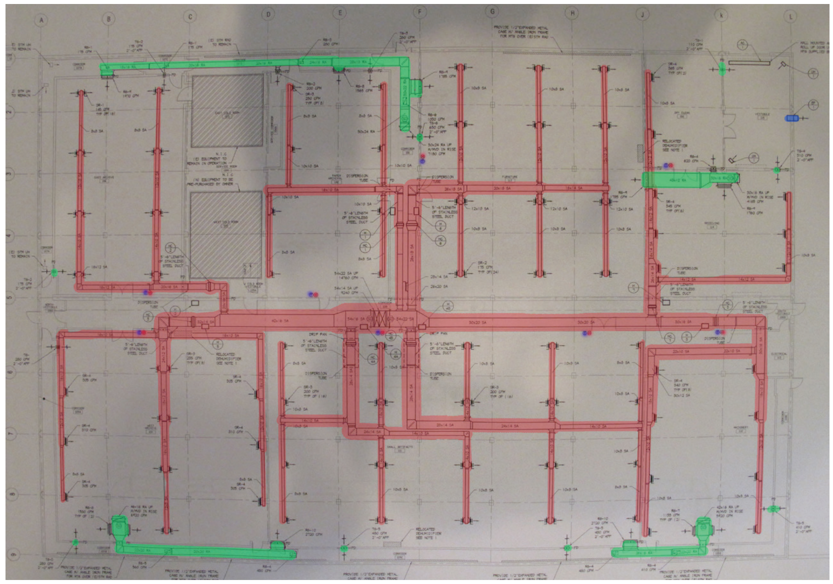
MARK	COOLING DATA: CHILLED WATER: NO.	ENT. TEMP °F	LEA TEMP °F	GPM	PD.-FT	FRESH AIR MIN. %	AIR: FACE VEL. FPM	ENTERING D.B. °F	ENTERING W.B. °F	LEAVING D.B. °F	LEAVING W.B. °F	REFRIG. LOAD: TOTAL M-BTU	SENS. M-BTU	TOTAL TON	COOLING COIL CFM	REMARKS
ACU-1	1	45	55	368	—	25	550	82.3	67.7	54	52.2	1,840	1210	153	39300	
ACU-2	1	45	55	377	—	25	550	82.3	67.7	54	52.2	1,880	1220	157	40200	
ACU-3	1	45	55	226	—	25	500	80.2	65.8	53	51.4	1,122	772	94	26300	
ACU-4	1	45	55	135	—	25	600	79.8	65.1	57	55.2	671	546	56	22205	

Sensor Placement

- Space temp sensor location: Note the location of any thermostats used by this unit.
- Space RH sensor location: Note the location of humidistats used by this unit if any.
- Where supply air enters space: Note where the supply air is exhausted into the space.
- Where return air leaves the space: Note where the return air is pulled from the space.
- Powered exhausts: Note if there are any powered exhausts in the space (normally connected to bathrooms or kitchens).

It may be beneficial to create a detailed map using specific colors to highlight:

- Return Ducts
- Supply Ducts
- Exhaust Ducts
- Thermostats
- Humidistats



Extra Heat Sources

- Extra heat/moisture sources: list any additional heat or moisture sources that may be found in the space.
- Perimeter radiation: can be found by walking the interior perimeter of the facility. List any sources of perimeter heat.
- Portable heaters: are there any portable heaters that are used in the space?
- Occupancy: The rough count of people that occupy this space and how often.

Lighting

- Knowing the lighting in your space will help provide insight into additional energy load and heat load that is in you space.
- This may require you to walk though the space and count fixtures. Check the number of lamps or bulbs per fixture.
- Most lamps or bulbs have their wattage marked on them. You can find the watts for each bulb by reading the end of a bulb.

- To calculate the watts per fixture multiply the watts per lamp or bulb by the number of lamps or bulbs per fixture.
- To find the watts sub-total multiply the number of watts per fixture by the number of fixtures (count).

Architecture

- Select any of the elements that pertain to the space.
- Be sure to add any notes regarding the features as well. It is important to note signs of deterioration like efflorescence, cracked windows, leaking roofs, etc.

Dataloggers in Unit

- Be sure to record the datalogger number used with the correct section of the unit it is covering.
- Always watch the placement of the dataloggers to ensure they are providing the most accurate reading possible.

HVAC System Documentation Worksheet

Building:

Completed By: Date Completed:

Mechanical System Notes

Location: Type: Manufacturer: Model:

Serial Number: BMS system:

Filter Capability

Type of filter: ☐ None ☐ Pre-filters ☐ Bag ☐ Box ☐ HEPA ☐ Charcoal ☐ Gas-phase

MERV Rating:

Cooling/Dehumidifying Capacity

Type of cooling: ☐ None ☐ DX ☐ Chilled Water ☐ Desiccant ☐ Other

Entering water temp:

Leaving water temp:

☐ Designs: Leaving WB: Leaving DB: DP:

☐ Face and Bypass:

Heating Capacity

Type of heating: ☐ None ☐ Gas ☐ Electric ☐ Steam/ Hot Water

Heater location: ☐ Preheat ☐ Before cooling coil ☐ After cooling coil

☐ Reheats

☐ Mixing boxes

☐ Terminal VAV reheat

Humidifier Capacity

Type of humidifier: ☐ None ☐ Steam (Boiler) ☐ Steam (generator) ☐ Ultrasonic

Humidifier location: ☐ Preheat ☐ Before cooling coil ☐ After cooing coil

Desiccant Type

☐ Desiccant wheel ☐ DX ☐ Liquid desiccant ☐ Air dryer ☐ Portable commercial
☐ Portable residential

System Controls

☐ Pneumatic ☐ Digital controls ☐ Combination ☐ Other: ______________________

Fans

Return fan:
CFM: Motor HP: Motor in Airstream: Hand AMP reading: VFD:

Supply fan:
CFM: Motor HP: Motor in Airstream: Hand AMP reading: VFD:

Relief fan:
CFM: Motor HP: Motor in Airstream: Hand AMP reading: VFD:

Condensing Unit

☐ Air cooled ☐ Evaporative ☐ Water-cooled

Operational Settings

Daily settings: Setbacks:

Set Points

Summer settings: Winter settings:

Damper Type

☐ Fixed ☐ Motorized Position ☐ Relief air

Air Flow

☐ Total airflow: Airflow over coils:

☐ Heating coil:

☐ Cooling coil:

☐ Outside air (design):

☐ % Bypass:

☐ Economizer:

Sensors

Space temp sensor location: ____________________

Space RH sensor location: ____________________

Zones/Area Served

Note where supply air enters the space: ____________________

Note where return air exits the space: ____________________

Are there powered exhausts from space? ____________________

Extra heat/ moisture sources: ____________________

Perimeter radiation: ____________________

Portable heaters: ____________________

Other equipment: (computers, humidifiers, grills, etc.) ____________________

Occupancy:

Actual: ____________________

Design: ____________________

Lighting:

Lamps Per Fixture	Watts Per Lamp	Watts Per Fixture	Count	Watts Sub-total

Total: ______________

Architecture

☐ Exterior walls ☐ Windows to exterior ☐ Doors to exterior

☐ Doors to interior spaces ☐ Ceiling/Roof exposed to weather ☐ Floor exposed to weather

Loggers in Unit

☐ Outdoor air ______________

☐ Mixed air ______________

☐ Cooling coil ______________

☐ Heating coil ______________

☐ Supply air ______________

☐ Return air ______________

☐ Humidifier ______________

☐ Space/Room ______________

☐ VFD ______________

Problems or Issues Noted:

____

____

____

____

____

____

____

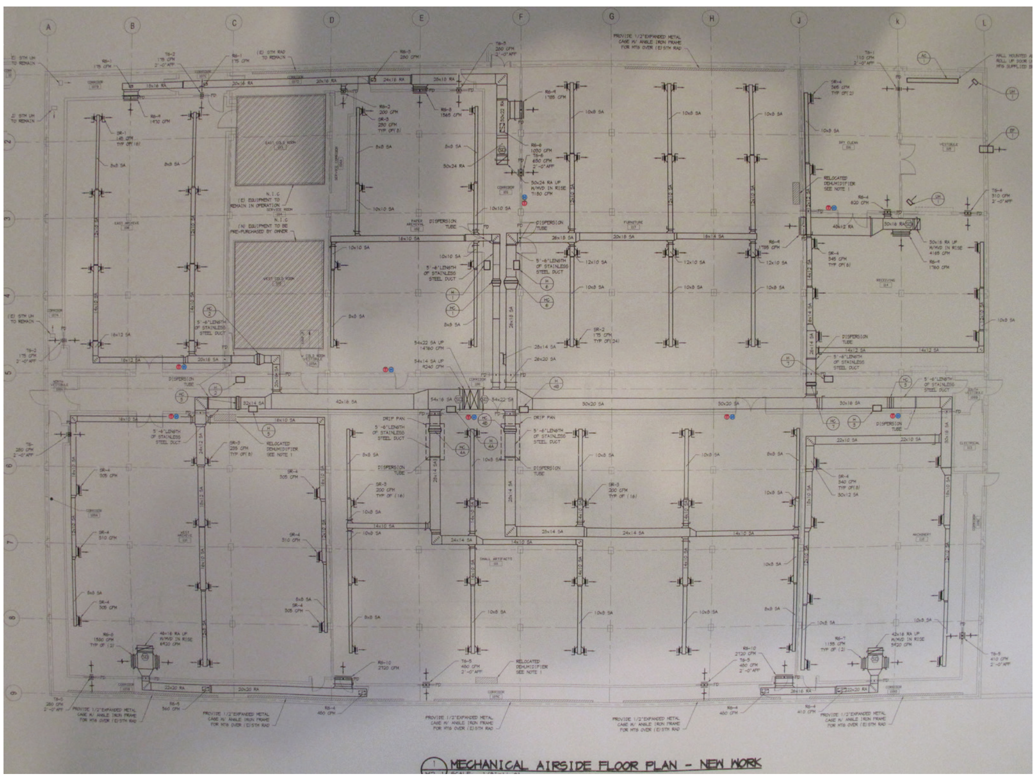
Creating Zone Maps

Zone maps can:

- Be useful in locating what air handler serves what section(s) of the building
- Point out where supply air from different air handlers serves the same area
- Show spaces served by the same air handler that may require conflicting conditions

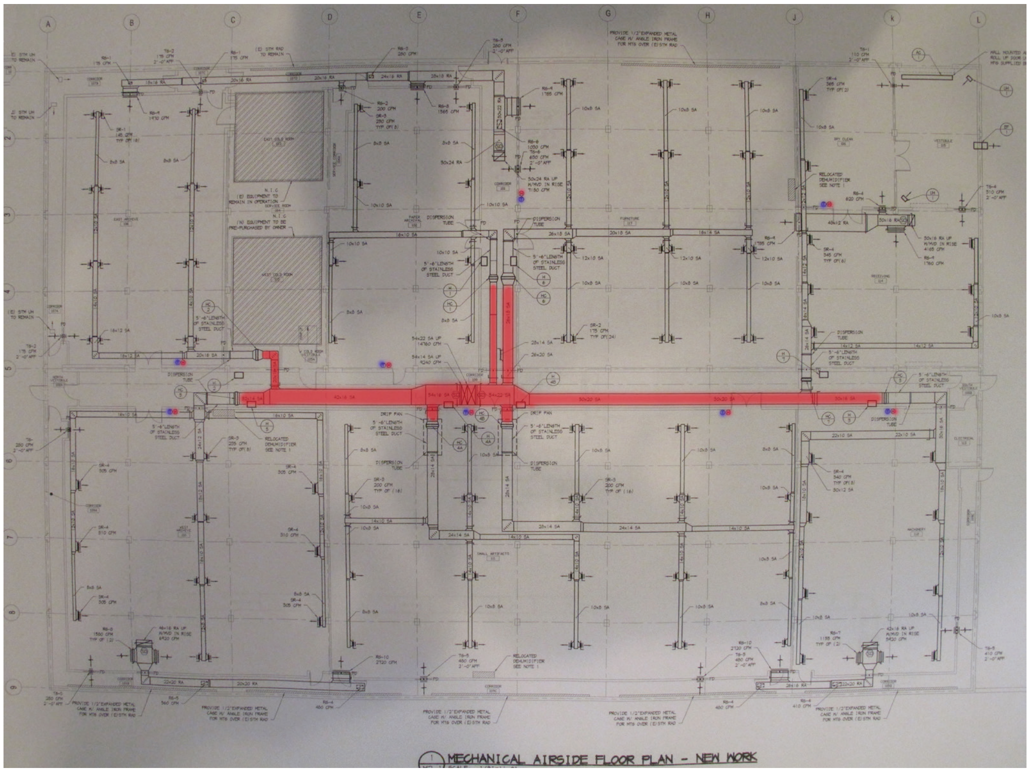
With Prints

If you have a set of blueprints that are considered reliable, making a zone map is a straightforward process. Look through your facility's M series of blueprints and identify the prints showing the location of mechanical systems and the ductwork layout. These will look similar to the image below. Make photocopies of these prints to make notations on, to avoid marking the originals.



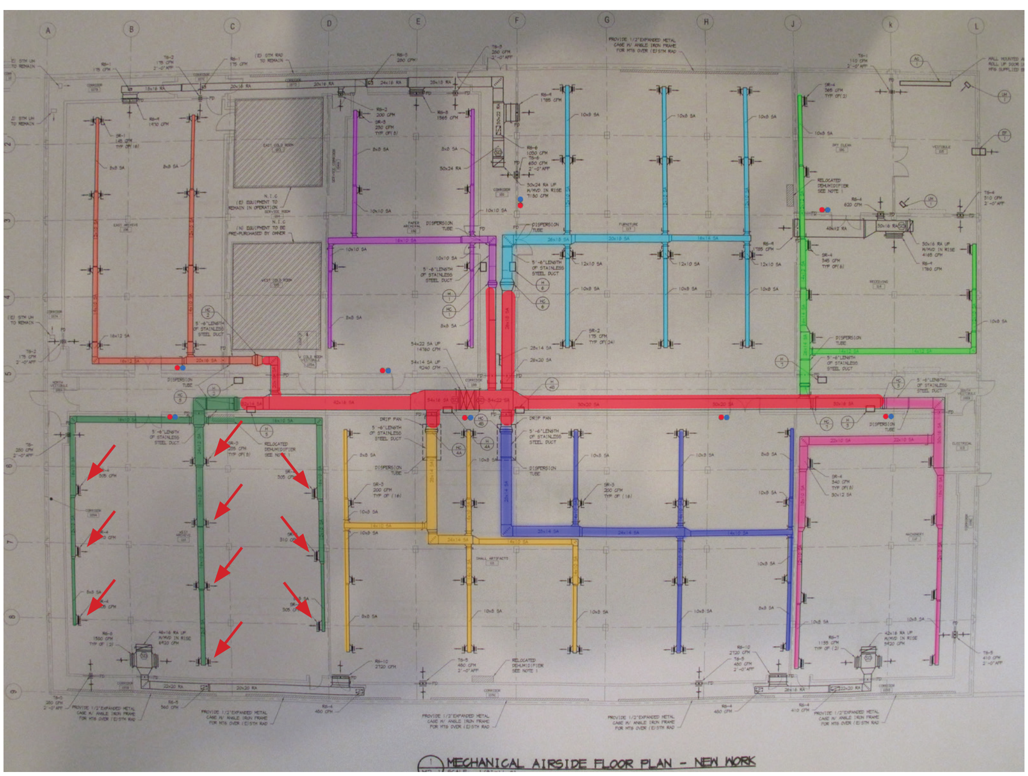
Begin by finding the location of your mechanical systems. If you know where they are located in the building, you can use the floor labels to help find the appropriate print; for example, many air handlers are located in the basement, so the plan labeled "basement" would depict the mechanical system.

Start with a single air handler. By looking at the system in person, you can determine where the return air enters the unit and where the supply air leaves the unit. On the print, follow the supply air, marking it with a highlighter or colored pencil, until something interrupts the line. In the following example, the main duct is marked in red until it reaches VAV boxes; this red area represents the ductwork carrying air at the same conditions, created by the main unit. Each VAV box can create different conditions downstream, so each branch after a VAV indicates a separate zone.

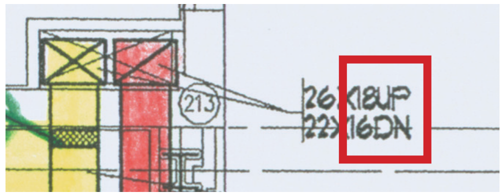


You may not have downstream equipment; in that case, all spaces receive the same conditions from the main unit, and the main supply line would continue directly into the spaces it serves.

Mark all branches off the main line using different colors until each one terminates. When you see a rectangle on the line (labeled below with red arrows), this is the location of a diffuser supplying air into the space.

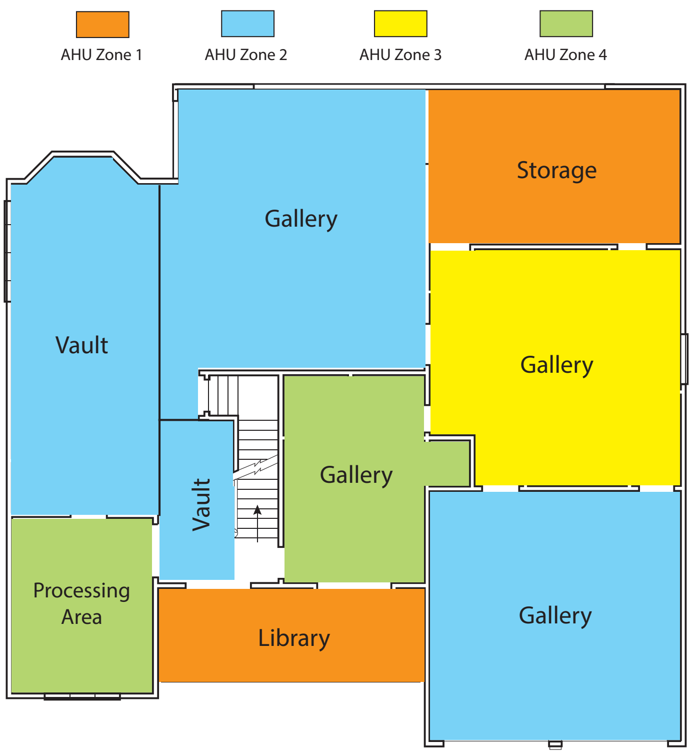


When the line extends to another floor, this is often indicated on the print with text (outlined in the red box below); locate the print for the adjoining floor and continue following the line.



This process can be repeated for any or all air handlers. Be sure to use different colors and keep track of what each color indicates. When you have finished tracing the ductwork, you can add in details, such as the thermostat and/or humidistat location in each space (usually indicated on prints with a "T" or "H" inside a circle, refer to the print legend for the correct symbol), and where return grilles and ductwork are located. These can be helpful details during data analysis, as they may provide clues as to why a sensor in a space is reading differently than others and causing the air handling unit to try to create different conditions. Knowing where the return grilles are in relation to the supply vents will help you evaluate airflow in the space.

You may find when you are done that it is easier for you to understand what is going on by transferring this information to a copy of the floor plan. While looking at the ductwork you traced, you can color code to indicate the branch or air handler serving each space. The example below shows how a supply line from a single AHU branches into four zones to serve nine different spaces.



Keep in mind that the air from any diffuser will extend to the walls of the room. Therefore, if branches from different air handlers serve a single space, the air will be a combination of the conditions of the multiple units and you will need to indicate this (ex. use both colors or only color in sections of the room in each color). Additionally, it may be of benefit to note on the zone map where air could pass between spaces, such as doorways between rooms.

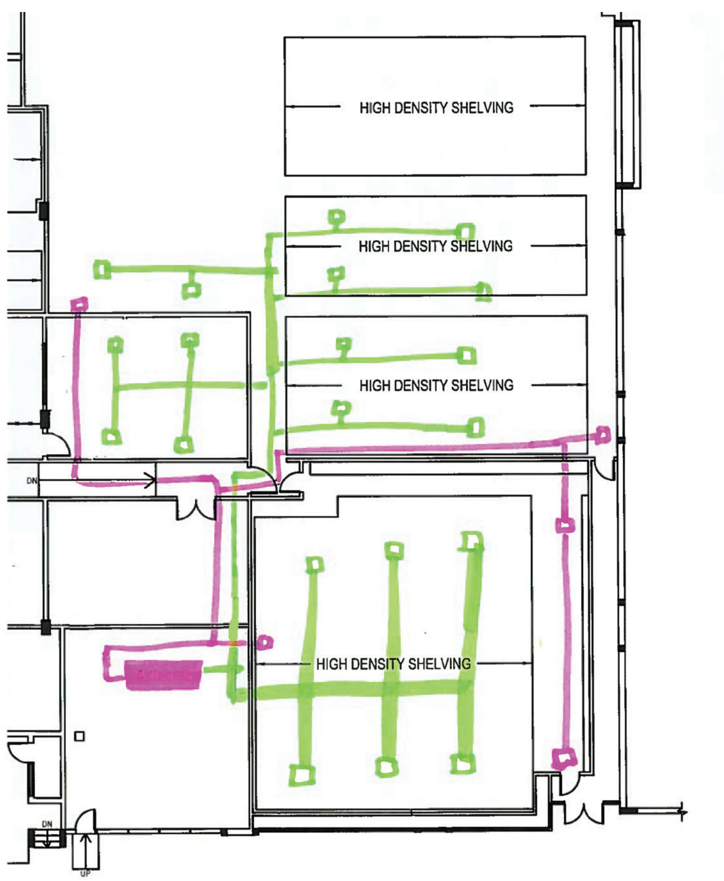
Without Prints

Creating zone maps without prints can be done but requires a bit more time and legwork. You will need:

- Access to the HVAC system
- A ladder
- A flashlight
- A blank floor layout. This does not need to be a blueprint, and could be something as simple as a photocopy of the fire exit map.
- Different color pencils or highlighters

Begin by marking the main unit's location on you map. Follow the supply ductwork out of the unit visually while in the space, and draw it onto your floor plan. Continue to follow the ductwork until it gets to the diffusers in the spaces. It may be necessary to move ceiling tiles to follow the ductwork as you go.

Below is an example of a zone map that was created without using blueprints. The large pink square represents the air handling unit, the green lines represent the supply duct lines, and the pink lines represent the return duct lines. The boxes represent diffusers, where the air is discharged from (green boxes connected to a green supply line) or pulled into (pink boxes connected to pink return lines) the unit.



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**.

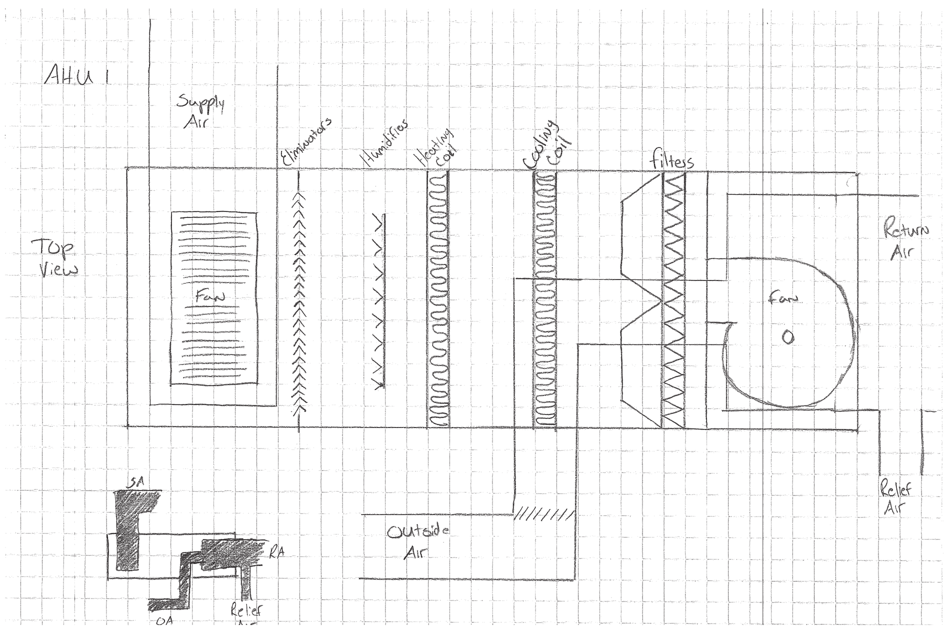
The following outlines the steps for setting up a monitoring program within an air-handling system. No two systems are exactly the same; each unit will require some thought regarding appropriate installation of dataloggers.

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.

METHODOLOGY:
DATA ANALYSIS

Once the data is gathered, the next step is to understand what it can tell you about preservation quality for the collection and the performance of the space and mechanical system. The ability to spot trends in temperature and relative humidity data, analyze them for preservation meaning, and begin to interpret the mechanical operations are skills that come with time and get better with experience. Analysis is a great exercise to go through with the entire environmental management team. Different people will catch different patterns, and questions from others can call attention to preservation risks or operational inefficiencies. As you move further into sustainable preservation and optimization, you will find that you keep going back to the graph. Data can show the symptoms of sub-optimal operation, can help diagnose where the problems exist, will tell you whether your efforts to correct issues are working, and will help quantify the impact of experimentation and testing.

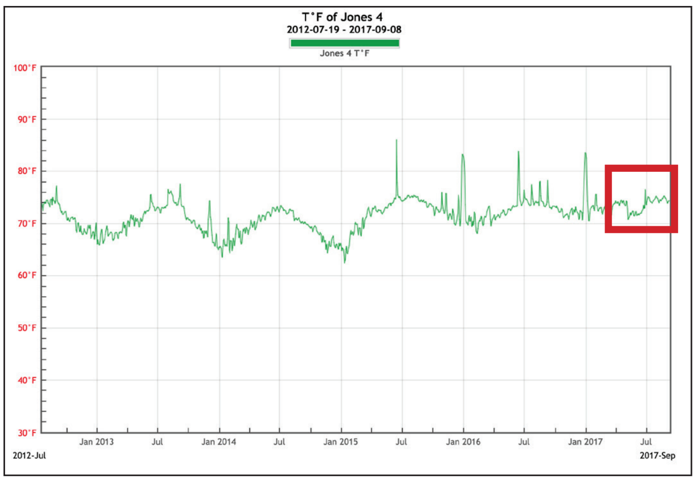
Chapter 6 in *IPI's Guide to Sustainable Preservation Practices for Managing Storage Environments* is an excellent introduction to data analysis for optimization; rather than repeat it here, this section will provide some additional practical guidelines, a few additional concepts for thinking about preservation analysis, and some simple models that illustrate inefficiencies.

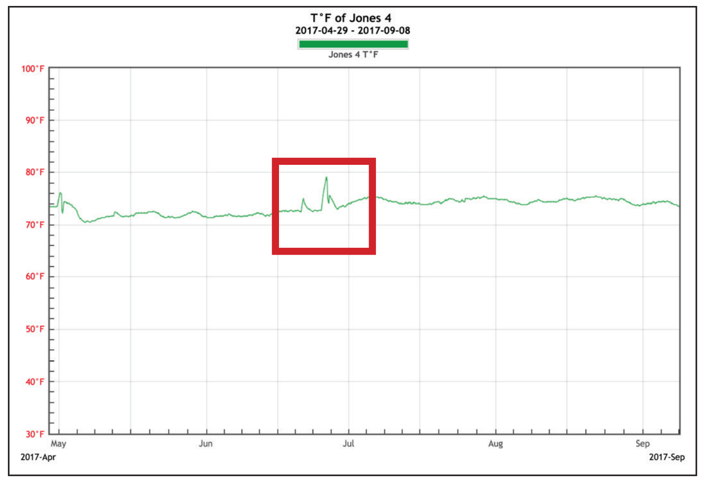
A few guidelines for making data analysis easier:

- When working as a team, or even individually, try to project the data on a wall or large screen.
- Focus on one space or one air-handler at a time.
- Begin by looking at a single dataset – be clear on what the pattern is before you move on to the next, or view multiples at once.
- Generally, it is easier to look at temperature and relative humidity individually to begin with, as opposed to on the same graph. Once you see the individual patterns, then overlay them to see if spikes or events correlate.
- As you gain experience, consider starting with the dew point graph – the moisture control capability of the system will often dictate environmental conditions.
- Look to see whether the mechanical operation makes sense for what the collections environment experiences.
- Always strive to confirm what you believe you see in the data – if it looks like there is a shutdown or a programmed schedule, check the controls programming to see if they are there.
- Data patterns can sometimes have multiple causes – make a list of the possibilities and work to eliminate them through space and system inspection.

Working with Graphs

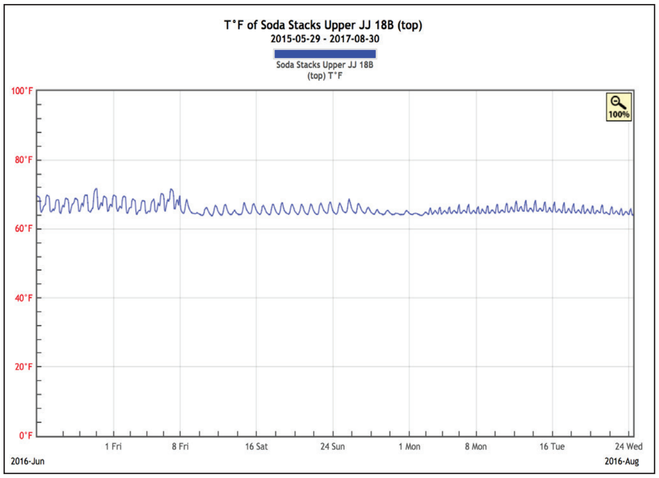
The process of working with graphs can often create interpretation issues for team members who have not worked with environmental data before. In most graphing packages that come with dataloggers, the temperature or relative humidity will be on the vertical, or Y-axis, while the horizontal X-axis will represent time. Manipulating the scale on either axis can benefit the analytical process in different ways. Looking at a long span of time – a year of data or longer – can be helpful for recognizing seasonal patterns such as high and low RH and poor moisture control. However, the more data (or longer time span) that is displayed, the greater the likelihood that some data compression will begin to come into play. Due to limited display sizes and the tens of thousands of data points that may be involved, different programs will begin to drop or average out data points in order to generate the graph – short events, spikes, and extreme conditions may no longer be seen. Looking at shorter time spans – days or weeks – can help illustrate particular events such as power outages, daily temperature trends, or data spikes that can then be analyzed. All the graphs illustrated in this section were generated by eClimateNotebook.

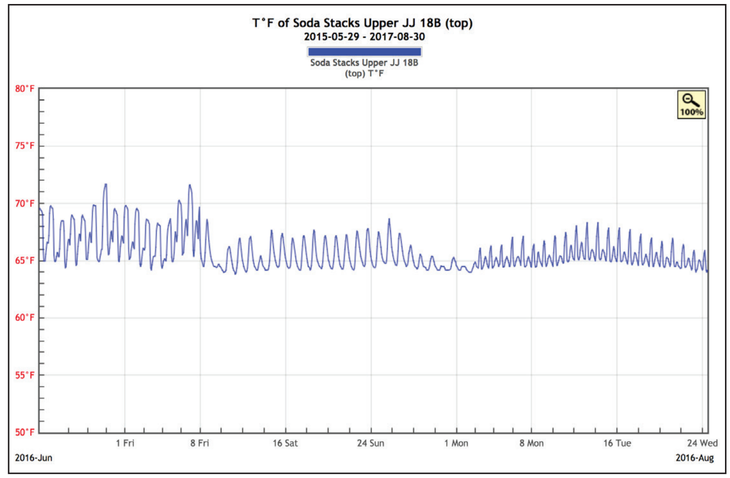




Together, the two graphs above illustrate the value in analyzing both extended and shorter amounts of data. The graph on the left represents over four years of environmental data. In this extended view, seasonal trends are visible, but a power outage that occurred on June 30, 2017 is not visible. In the graph on the right, analyzing four months of data from 2017 allows the software to display the impact of the power outage.

Working with scale on the vertical axis – usually temperature, relative humidity, or dew point – can have a similar effect. Many graphs will have a default Y-axis scale of 0-100 for %RH or °F. This can be helpful for watching macro trends or relative seasonal conditions, but when the question is how many degrees a particular space may fluctuate during a shutdown or setback, or how much work is being done to the air from one mechanical component to the next, working with reduced scales – for example between 50-80°F or 20-70% RH – can allow better visual quantification of the data patterns. Always remember to watch the scale at which the data is displayed – problems can be missed by only looking at date on a larger scale, and small variations of a degree or two can become panic-inducing if viewed at a small scale.





Together, the two graphs above illustrate the impact of changing the scale on environmental data graphs. The graph on the left represents a temperature scale of 0°-100°F and daily fluctuations appear to be only a few degrees at first glance. In contrast, the graph on the right represents the same data at a smaller temperature scale of 50°-80°F and the range of 2°-7° fluctuations is easier to interpret.

The three most significant psychrometric values that influence our interpretation of sustainable preservation environments are dew point, temperature, and relative humidity. The psychrometric relationships between the three are examined closely in Chapter 5 of *IPI's Guide to Sustainable Preservation Practices for Managing Storage Environments*. This methodology guide focuses more closely on the analysis and interpretation of that data when graphed.

Dew Point

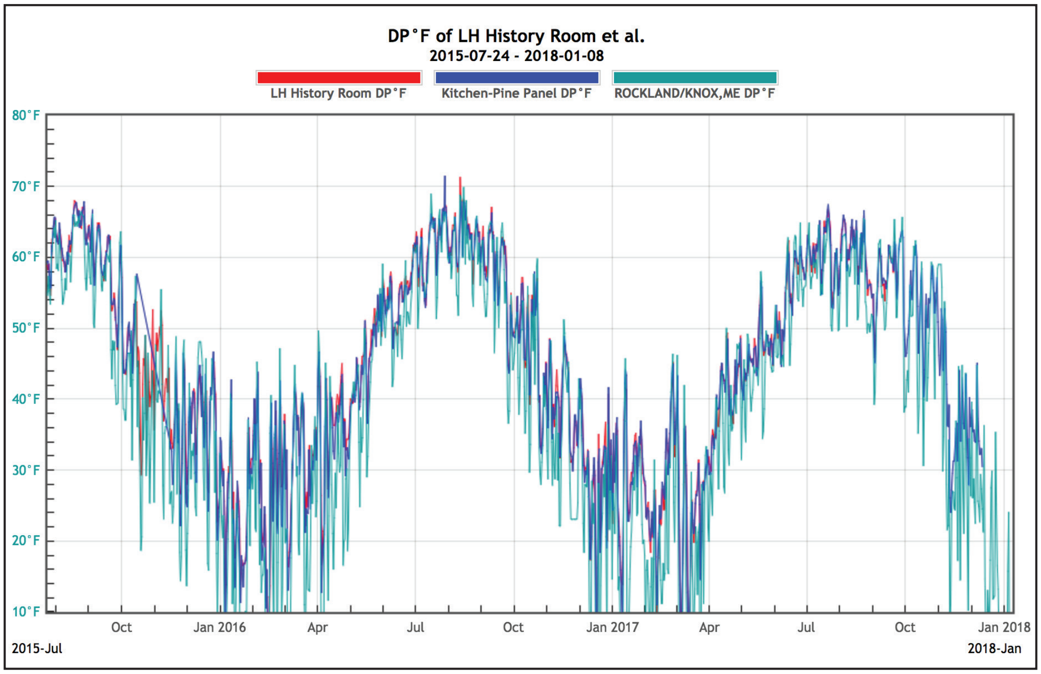
The dew point temperature is the temperature in the environment where the air is completely saturated with moisture – as the air cools below this temperature, moisture in the air will condense. It is a measure of the absolute amount of water in the air, and is what determines the type of environment that will ultimately be created in collection spaces. For example, if you wanted 40%RH for preservation:

- at a 45°F dew point, the temperature will be 70°F (human comfort); and
- at a 30°F dew point, the temperature will be 54°F (more appropriate to a storage environment).

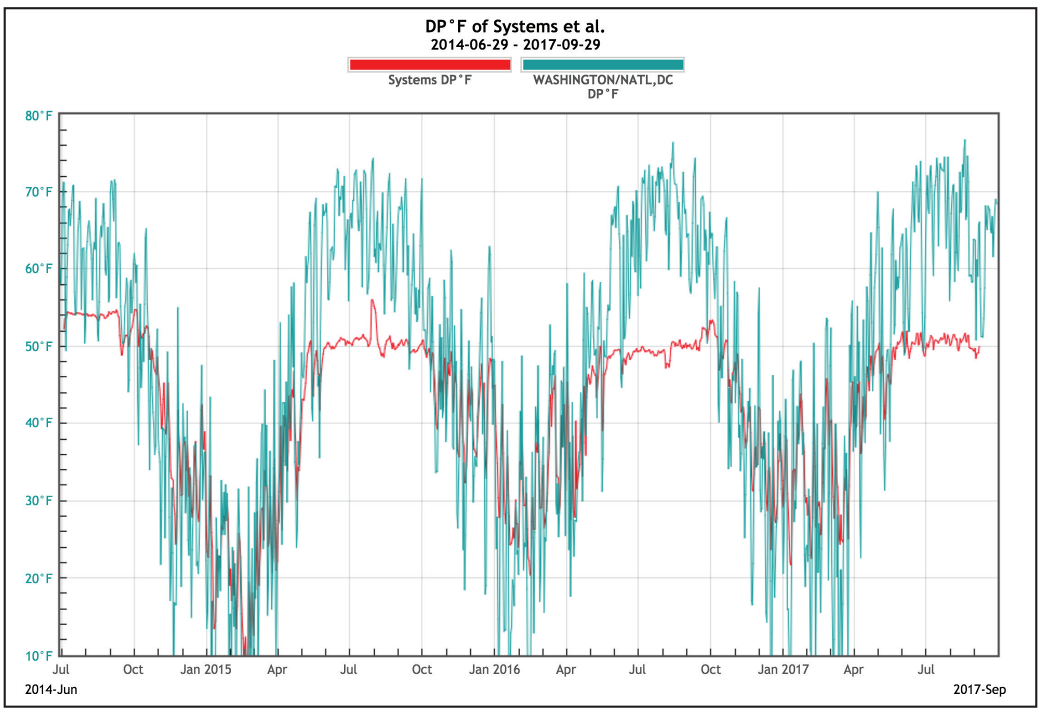
Having a lower dew point allows for temperatures to be lower while still maintaining appropriate relative humidity levels, which is critical for ensuring long-term preservation. Beyond the preservation implications, from a mechanical perspective, the ability to control dew point is often the limiting factor of a mechanical system's ability to provide a particular storage environment.

Dew point graphs can be particularly helpful in understanding three key behaviors:

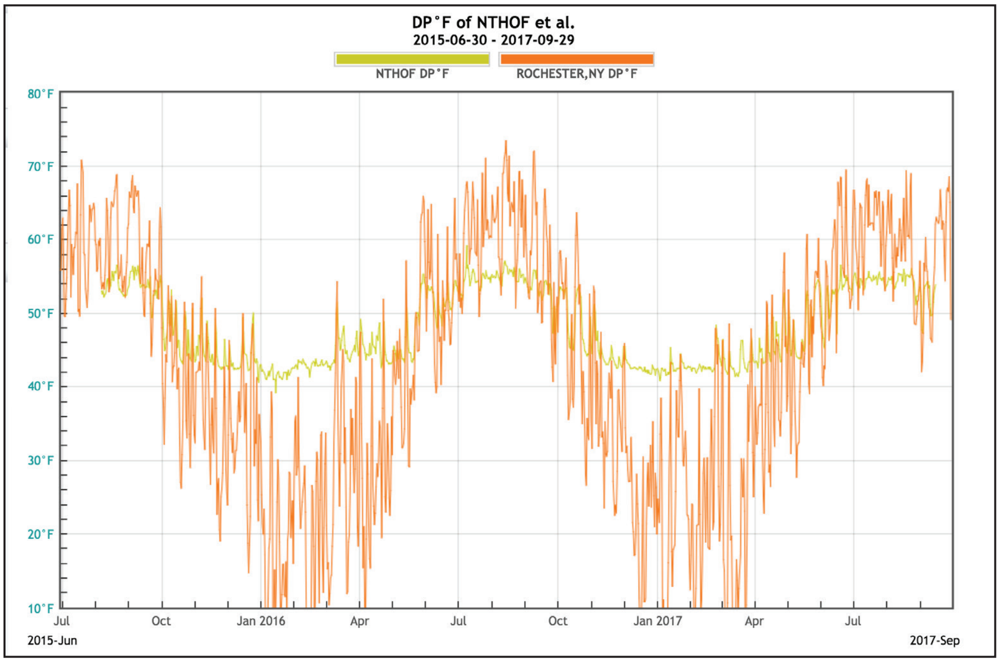
1. The influence of the outside environment on the collections environment – when comparing indoor and outdoor dew points, the closer together they are, the less moisture control is being performed (see graph on the following page). Buildings without mechanical systems will have indoor dew points very similar to the outdoors.



2. The ability of the mechanical system to dehumidify, or remove moisture from the air. This will often result in a "ceiling" on the dew point graph when exterior conditions are humid, with the interior dew point leveling off as the outside dew point continues to fluctuate (see graph below).



3. The ability of the mechanical system to humidify, or add moisture to the air when exterior conditions are dry. This operation will often show a dew point graph at a higher condition than exterior dew points, but without the flat nature of a summer dehumidification graph due to the control point being %RH in the space, rather than actual dew point (see graph on following page).



In addition, comparing dew points from different parts of the building with each other can help to determine which system(s) affect the spaces and confirm/refute the zone map. If spaces are served by the same mechanical system, the graph of their dew points will be the same, something of a dew point "signature" of the unit. Different dew point conditions among spaces typically indicates that they are served by different mechanical systems – it is unlikely that two AHUs could maintain exactly the same dew point control. Keep in mind that different dew point conditions within the same physical space may indicate that it receives air from multiple units, or the presence of a downstream humidifier or other equipment to control a local microenvironment.

Temperature and Relative Humidity

Graphs of temperature and relative humidity of spaces can be examined to ensure that these parameters are within the set ranges, and, at the assessment stage, confirm that seasonal set points or other changes have been appropriately implemented. Beyond preservation concerns, both can be particularly useful in evaluating mechanical operation and energy implications.

The issues of scale discussed earlier are particularly significant when interpreting the data available – various views will reveal different influences. Examining data on a small scale will likely show day-night fluctuations that illustrate patterns of occupancy. People, lights, computers, and other components all add heat to the spaces they occupy. If a room has windows or is just below a roof, afternoon solar gain may be visible in the temperature graph.

Temperature in particular can be useful in tracking changes and identifying problems. Sharp changes in temperature can indicate equipment malfunction or a set point change, whereas a more gradual change can be indicative of seasonal changes or limitations in capacity. These will show up on a relative humidity graph as well, but it may be longer before it takes full effect and may be more difficult to discern from usual fluctuations, since relative humidity is generally less consistently maintained by mechanical systems than temperature.

It is also possible to determine the load in a space by comparing the supply air with the return air. If the return air is warmer than the supply air, the space adds heat and there is a cooling load; if the return air is cooler than the supply air, the space removes heat and there is a heating load. Typically, collection spaces should have little to no load, but surrounding spaces can influence this.

Relative humidity graphs are useful in evaluating preservation risks such as metal corrosion, physical damage due to expansion and contraction, and the potential for mold growth, but are also the key indicator of humidification operation, and can signal issues with dehumidification if the temperature has remained normal. Remember that relative humidity is a function of the dew point and the temperature – if you see problematic fluctuations in relative humidity, look to see which of those two values may have changed, and trace the change back to its cause.

Outdoor Weather Data

Using outdoor weather data is often less about analyzing the outdoor weather itself – although understanding seasonal trends and how they may change over time can be valuable for planning strategic operation – and more about what it indicates about building and system performance. As mentioned earlier, overlaying indoor and outdoor dew points can help visualize the amount of moisture control that is performed. From a planning perspective, using an outdoor dew point graph with proposed dew point control settings overlaid as limit lines can also help visualize the comparative amounts of work that might be necessary.

Always consider the relative accuracy of the outdoor weather data available – if it is not gathered onsite via a datalogger, BMS sensor, or other source, there may be key differences between exterior conditions at the institution and the closest dataset available. eClimateNotebook uses data from the National Oceanic and Atmospheric Administration (NOAA) weather stations at regional airports, but even weather data from a few miles away can be different from what occurs at your site depending on elevation, wind patterns, or large bodies of water.

Preservation Analysis

When dealing with collections environments, the first step of actual data analysis will typically be critically examining the temperature, relative humidity, and dew point conditions for both short- and long-term risks to the collection in the space. Each of these qualities has different implications for collections preservation. This section will delve a little further into various ways to analyze and interpret that data.

Implications for Preservation

In analyzing environmental data for the purposes of preservation, it is important to keep in mind that the overall impact on collections is determined by the amount of time spent at each condition. Broad seasonal trends matter more than sharp peaks of brief duration. However, for sustained periods at a given set of conditions, periods of higher temperatures or extremes of relative humidity have a greater impact on the rate of deterioration than those in appropriate ranges.

In IPI's resources, this is demonstrated by the TWPI – time-weighted preservation index. The higher the number, the longer the material can be expected to last without noticeable deterioration. This is based on experiments with fresh rolls of acetate film. Other film and archival material were found to have similar activation energies, and these are believed to adequately approximate the average response of these sensitive organic materials.

One use for TWPI is to compare different collection spaces. If one collection space is significantly different than another, it may be a better candidate for storing more sensitive materials (other risks must be taken into account). It may also help to inform decisions about which spaces are in need of upgrades, improvements, or replacement.

Materials in collections will have often been exposed to a range of environmental conditions in the past. This makes estimating the effects of the environment on specific materials difficult. Proofing has been a suggested concept for further understanding mechanical decay. For example, once wooden furniture has experienced a low enough humidity to cause shrinkage resulting in cracking, returning to that same low humidity will not cause additional cracking because the material is now free to expand to that degree. In regards to chemical decay, for materials that have already experienced some degree of chemical decay so even standard storage conditions may not be adequate to ensure their long-term preservation. An example of this is acetate film that exhibits advanced vinegar syndrome – only frozen storage provides the environment necessary to slow the deterioration.

Much of the value in preservation analysis is added by the collections care professional who understands the types of materials present in their collection and their histories. There are four major types of environmental decay: chemical, mechanical, corrosion, and mold. These relate to other types of deterioration, such as pest activity and the effects of pollutants and light. In general, all of these risks are greatest at high temperature and humidity levels but for different materials, the risk from a type of decay will vary. For example, book collections may be more vulnerable to mold than corrosion. Knowing where to set environmental parameters and when the analysis indicates a preservation issue is informed by the specifics of each situation.

Preservation Analysis for Collections Risk

While eClimateNotebook provides access to IPI's Preservation Metrics and the built-in risk indicators for chemical degradation, mechanical damage, metal corrosion, and mold risk, basic environmental risk analysis can be performed based on recognizing where certain types of degradation tend to begin. Like the Preservation Metrics, these analysis strategies are not meant to be diagnostic – rather, consider them as warning indicators of potential issues. Issues that are spotted in data may not have caused damage yet, but often will if left unchecked. Likewise, environmental data is limited in that the readings only apply to the immediate environment of the datalogger or sensor – microclimates often exist, and can run counter to the initial analysis.

CHEMICAL DEGRADATION

Standards for what constitute "safe" conditions for organic collection materials vary throughout the professional literature; most current standards recognize that rates of decay occur along a spectrum, with warmer temperatures being more risky and cooler temperatures being safer. What is appropriate is deemed the responsibility of the institution to decide, based on their own individual circumstances.

Generally, if preservation environments typically run at temperatures higher than 68°F, organic materials may be at high risk for chemical decay. Broadly defined – if a collections environment is being controlled to provide human comfort, it is likely that the rate of chemical decay is too fast for long-term preservation. Cooler temperatures and moderate relative humidities are generally better, with temperatures between 40-67°F generally providing appropriate preservation depending on the type of material in question. For certain sensitive media – specifically acetate film and color media – long-term chemical and color stability require even colder temperatures, with temperatures below 32°F recommended for long-term storage. However, for other materials, freezing and below is not recommended.

Relative humidity also plays a part – as RH increases, the rate of chemical decay increases, and as it decreases, so do chemical decay rates. This relationship is often visible when looking at Preservation Index (PI) and TWPI numbers on a seasonal basis, when chemical decay rates can fluctuate with RH conditions, even if the temperature remains the same.

MECHANICAL DAMAGE

Mechanical damage is expressed in the Preservation Metrics as % Equilibrium Moisture Content (%EMC), but in practical data analysis terms when working with graphed environmental data, the critical input is the RH graph. When looking at RH trends, issues with mechanical expansion and contraction begin to occur at conditions higher than 60% and lower than 30%. Again, these limits can vary depending on specific media types and construction, and previous environmental conditions and deterioration. Risk of mechanical damage increases the longer that an item is at the potentially damaging condition, which is why seasonally low or high RHs are of particular concern. Moisture equilibration rates for various materials, how they are stored, and previous damage experienced (proofing) can all play significant roles in the amount of actual shape change experienced.

METAL CORROSION

The four most common oxidizable metals in collections are iron (steel), copper, bronze, and silver. Actual oxidation reactions for each begin at various points, but risk for corrosion generally begins when objects are exposed to 55% RH or higher for extended periods of time. While museum collections may have obvious risk for metal corrosion, metal content can often be overlooked in other collections, particularly those with library and archives materials. Black-and-white, silver-based photographs, books including metallic elements such as hinges and clasps, and fasteners in archival collections are all either at risk or could cause damage to portions of the collection due to metal corrosion.

MOLD RISK

Like metal corrosion, mold germination on different materials can occur at different rates based on multiple factors – the equilibrium moisture content of the object, the % RH of the environment, temperature, and time all play a part. Aside from disaster scenarios – flooding, burst pipes, or other soaking of the collection – most mold outbreaks occur when RH levels are at 70% RH or higher for extended periods of time.

Operational Analysis

Placing dataloggers within the mechanical system or using trended data from a BMS allows for the analysis of work done to air throughout the mechanical process. Analysis of data for mechanical operation and energy consumption is driven by three primary questions:

1. What preservation environment is the existing system capable of delivering?
2. What preservation environment is the existing system actually delivering?
3. Is the system consuming more energy than necessary to deliver the desired environment?

The first question is often answered (at least partially) by the documentation phase. Careful study of the design drawings, mechanical equipment schedules, and control set points can often illuminate not only the design capability, but whether there might be differences between the typical operational set points and what the system is capable of. Sometimes documentation will indicate that system capability is greater than current operation – determining whether this is true can be part of the experimentation and implementation phase. The second question is addressed in the preservation analysis outlined in the preceding section.

The third question is where critical analysis of mechanical data comes into play. To gain insight into energy performance requires an understanding of what the system SHOULD do – ie, should it be heating, cooling, dehumidifying, humidifying – based on its design and the known or presumed energy loads. What it should do then gets compared to what it is doing.

A few guidelines for making operational analysis easier (some of these will be familiar from the preservation data analysis section):

- When working as a team, or even individually, try to project the data on a wall or large screen.
- Focus on one space or one air-handler at a time.
- When working with mechanical data, always follow the air flow – this will be covered in greater detail.
- Begin by looking at a single dataset – be clear on what the pattern is before you move on to the next.
- Typically, you will want to focus on temperature and dew point graphs – RH conditions are partially determined by energy loads in the space, and are less reliable for operational data analysis.
- As you gain experience, consider starting with the dew point graph – moisture control is often the most difficult operation to perform.
- Look to see whether the mechanical operation makes sense for what the collections environment experiences.
- Always strive to confirm what you believe you see in the data – if it looks like there is a shutdown or a programmed schedule, check the controls programming to see if they are there.
- Data patterns can sometimes have multiple possible causes – make a list of the possibilities and work to eliminate them through system inspection.

Working with Mechanical Data

As discussed in the Gathering Environmental Data section, the types of mechanical data available can vary based on access to points in the air-handling unit, whether some of the data is coming from a BMS, and the design of the system in question. This step-by-step analysis description will use a common sub-cool and reheat designed system as an example.

Return Air

Return air and outside air are generally the first two datasets to inspect when beginning operational analysis. Return air can be a very close approximation of the actual collections environment, especially when the entire air-handling zone is dedicated to collections storage. When the zone is mixed-use (collections storage and occupied environments) the return air will represent a blend of the various conditions throughout the zone. The immediate goal is to compare the return air to the collections space conditions and determine the relationship between the two. When the entire zone runs at the same set point conditions, the return air is often used as a control point – temperature and moisture control at the coils and the humidifier will vary in order to achieve the correct return air condition.

In a mixed-use zone scenario, where, for example, part of the zone is kept at 60°F for preservation, and another portion is kept at 72°F for human comfort, inspect the data to see which temperature the return air favors. Ideally, the return will be a representative blend based on how much supply air each space receives, but it is common to see the return air biased toward one condition or another, implying that one of the spaces may not have enough return pulled from it. This can occasionally impact both space and energy performance.

Outside Air

As with preservation analysis, outside air conditions have a distinct impact on mechanical operation and performance. In many cases, the vast majority of the moisture and filtration load that a system has to control is brought in through the outside air intake. If documentation has revealed the design quantity of outside air for the mechanical system in question, the temperature and dew point data will help quantify the load that the system has to contend with.

Mixed Air

The mixed air condition offers several opportunities for in-depth analysis of performance. As the blend of return air with any outside air is brought into the system, the energy (both sensible and latent) in this air volume is what the downstream components will have to work on.

Accuracy is very important when using mixed air for operational analysis; best practice in datalogger placement is typically to gather the mixed air data after filtration occurs, in order to achieve the best air-mixing possible.

Sensible *– A change in temperature, not a change in state. Temperature changes you can feel.*

Latent *- A change in state, but not a change in temperature, such as heat used to change water to steam.*

Mixed air graphs will usually reflect the blend of return and outside air. When the three (return, outside, mixed) are compared on a temperature graph, the mixed air plot will often fall somewhere between the other two. One common initial assessment is looking at that mixed air temperature trend with the design outside air quantity in mind. The mixed air should, to the eye, reflect the percentages of outside and return air. For example:

- If all three were flat-line temperatures, and the system was designed to use 50% outside air by volume, and 50% return air, the mixed air plot should be halfway between the two.
- If the system was designed to use 90% return air and 10% outside air, the mixed air plot should be slightly separated from the return air plot.

Occasionally, data will show the mixed air condition sitting right on top of the outside air condition. Presuming correct logger placement and a representative blend, this will often indicate the presence of an economizer control, where larger quantities (up to 100% volume) of outside air are brought in as free cooling.

From an energy perspective, the mixed air temperature plots are critical because they represent the loads on which the coils will have to work. If the mixed air is too warm and/or moisture-laden, the cooling coil will need to remove that energy; if the mixed air is too cold or dry, the heating coil and humidifier will have to work to create the proper condition.

Cooled Air

The cooled air dataset, typically taken directly after the cooling coil, reflects the amount of work done to the air by the cooling coil. Depending on the geographic setting, building characteristics, and collections environment set points, this work may be seasonal, year-round, or sporadic depending on outdoor conditions. The key is figuring out whether it is doing the correct work at the correct time.

Temperature and dew point graphs each reflect a portion of the total work done by the coil. A simple way to begin quantifying the operation is to compare the mixed air and cooled air condition for both temperature and dew point. On the temperature graph, if the temperature drops from the mixed air condition to the cooled air condition, this indicates sensible cooling performed, and can be quantified for basic energy analysis as "degrees of work performed". For example, if the temperature dropped by 65°F to 45°F, the cooling coil can be said to have done "20 degrees of sensible cooling." In HVAC control terms, this operation is simply referred to as "cooling" and may be performed independently, or may occur as a part of "sub-cooling" in a dehumidification operation.

The dew point graph may show a drop in dew point between the mixed air dew point and the cooled air dew point – this reflects dehumidification occurring. If the mixed air dew point enters at 50°F, and the cooled air condition is 45°F after the coil then the coil has performed "5 degrees of latent cooling" or dehumidification.

The combination of sensible and latent cooling performed is the "total" cooling, or work, performed by the cooling coil. In the above example, the total cooling is equal to 25 degrees – 20 degrees of sensible cooling and 5 degrees of latent.

The question to consider is whether this total amount of energy work performed on the mixed air makes sense for the operation of the unit. The above example would make perfect sense in many warm, humid environments or seasons, where dehumidification might be necessary. However, if the same total "degrees of work" were performed when outdoor conditions were cold and dry – when there was no need for cooling and dehumidification – that amount of work at the cooling coil might be an indicator that excessive energy is being used.

Heated Air

The heated air dataset can sometimes be a difficult one to name/label appropriately – sometimes it is simply heated air, sometimes it is "reheated" air, and, depending on the presence of a humidifier or other downstream equipment, it may be best described as the "supply" air. In any case, this dataset represents the condition of the air after it has been worked on by the heating coil. Typically, the critical graph for this dataset will be temperature. Mechanically, the heating coil has no means of changing the dew point condition of the air; if there is a change in dew point between the cooled air condition and the heated air condition, it may indicate poor logger placement for one of the dataloggers, influence from a close proximity humidifier, or, in rare cases, a leaking coil.

The analytical goal is to understand the work done by the heating coil through comparing the cooled air temperature with the heated air temperature condition. In many environments/locations, the heating coil will perform work year-round, for part of the year as reheat in a dehumidification mode, and for part of the year as strictly sensible heating to maintain space temperature (this is also the reason why the heating coil is often the single largest energy consumer in a mechanical system). The difference between the cooled and heated air temperatures will vary based on the necessary mechanical operation.

Like the mixed-cooled air analysis, the work performed by the heating coil can be expressed in "degrees of work;" unlike the cooled air, the work of the heating coil will always be in sensible energy. To revisit the previous example, the air leaving the cooling coil had a temperature of 45°F, and a dew point of 45°F. Analysis of the heated air dataset shows that the air was heated from the cooled air temperature of 45°F to 60°F, for 15 degrees of work. The dew point did not change. This is an example of reheat operation – the air is heated to bring the RH back to an appropriate level and provide the appropriate supply air condition.

Inefficiencies at the heating coil often occur as part of cold-weather heating, unnecessary from the perspective of preservation, and less often as part of the sub-cool/reheat process. Using the same year-round temperature set point in unoccupied preservation environments, especially during cool seasons, can lead to unnecessary heating and sub-optimal preservation and energy performance. In sub-cool/reheat scenarios, too much heat may be driving the RH in the space unnecessarily low. In a dehumidification operation, driving the space RH lower requires additional energy in the form of reheat.

Humidified Air

Humidification's primary influence on the air stream is an increase in the dew point; temperature changes, though possible with steam humidifiers, are not always present or detectable. Again, analysis of energy work and operation are based on the humidifier's impact on the air condition and whether it appropriately matches the preservation goal. Comparing the heated air dew point and the humidified air dew point will quantify the degrees of work in dew point increase – like dehumidification, this is working on the latent energy in the air stream.

High RH set points when outdoor conditions are dry are a common cause of sub-optimal humidifier operation. Historic standards which called for flat-line control of RH conditions year-round have resulted in many systems over-humidifying beyond any additional benefit to the collection.

Supply Air

The supply air condition is often the same as the heated air condition or the humidified air condition, but for the sake of illustration is treated separately here. The important relationship to consider for the supply air condition is how it compares to conditions in the preservation environment and the return air temperature. The supply air temperature and dew point can be compared with either the space conditions or the return air to determine the load in the space for both the sensible (degrees of temperature) and latent (degrees of dew point) energy. The quantity of those loads provides further insight into potential sub-optimal operation.

As a general rule, when the supply air temperature and dew point are significantly different than the space or return air temperature and/or dew point, the indication is that there is significant energy load that the system is trying to overcome, by either heating, cooling, dehumidifying, or humidifying. In single-use AHU zones (such as one that is solely for collection storage), as the supply air conditions and the space/return air conditions come closer together, the implication is that energy load is the space has decreased, whether from reduced exterior heat load, lights being off, reduced occupancy, or other reasons. Operationally, the message is that the system should be able to work less while still maintaining the environmental set points. These times, whether on a daily seasonal, or even year-round schedule if the zone is well-buffered from exterior conditions, are often excellent opportunities for testing. Analyzing typical heat and moisture loads in a space and a system over the course of a year can greatly assist in defining what sustainable operation might look like.

Other Considerations

The above sections provide a broad example of how mechanical data may be examined and analyzed. The specific comparisons will change slightly based on different system designs, equipment types and locations, and environments, but the general practice – follow the air, step-by-step, and examine the work done at each component – will hold true regardless of design or equipment. Documentation is key – once what the system is supposed to do is understood, analysis comes back to the third question: does the system use more energy than necessary to deliver the actual environment?

Recognizing Inefficiencies

The previous section gave several examples of inefficiencies that may be discovered through the process of mechanical system data analysis. While sub-optimal operation and inefficiencies are often discussed in terms of mechanical operation and energy consumption, it is important to note that preservation – meaning the quality achieved for the energy required – can be sub-optimal or inefficient as well. This section illustrates several common sub-optimal scenarios in collections settings, and what factors may help with their recognition.

Excess Outside Air

The amount of work performed by the system to modify the temperature and moisture content of outside air to match the desired supply air conditions is typically greater than the amount needed to condition return air from the spaces. Minimizing the amount of outside air used can reduce the energy used at multiple points in the system, including at pre-heating coils, cooling coils, and humidifiers, and can reduce the filtration load as well.

Many environments designed for collection storage with little to no human occupancy may have excellent thermal insulation and vapor barriers, and thus minimal energy loads – the introduction of outside air may be the only meaningful energy load the system has to work on. Even collections spaces that do not have strong building envelopes can often benefit from reduced outside air quantities, as it can minimize the energy load on the system and allow it to work more efficiently on energy loads from the space.

However, localities have legal outside air requirements for human occupancy. This may not be an issue if the space's primary purpose is storage, with no human occupancy expected. It may also be possible to add CO_2 sensors, which bring in more air as needed for people.

It is also important to note that outside air can be beneficial as in situations where off-gassing is a possibility and/or to maintain positive/neutral pressurization of the space.

Sub-optimal Environmental Set Points

Using lower temperature set points in cooler environments and seasons will require less energy for heating, may either improve low RH levels in situations where humidification is unavailable or reduce the need to humidify if exterior conditions are cool and dry, and can simultaneously reduce the rate of chemical deterioration.

Unnecessary Seasonal Dehumidification

Dehumidification, whether via a sub-cool/reheat operation, desiccant technology, or other equipment, is often the most energy-intensive operation a system serving a preservation environment performs. Maintaining this operation in seasons and conditions where it is unnecessary is a significant drain on energy resources. In rare cases, inappropriate dehumidification can actually remove moisture added to the air by a humidifier.

Recognition is fairly simple with cooling coil data or data from a desiccant system's processed air stream. Dehumidification is unnecessary if all of the below are true:

- If the current outdoor air dew point is lower than the dew point of preservation environment;
- if current outdoor air dew point is lower than the dew point of the cooled air or processed air;
- if the dew point does not drop from the mixed air to the cooled or processed air condition; and

- if the return air condition is at an equal or lower dew point than the supply air condition.

Keep in mind that some spaces will require sensible cooling – although not dehumidification – year-round due to heavy thermal insulation and interior heat loads from lights or other sources.

To quantify the amount of unnecessary work, examine the following:

1. Degrees of work performed for sensible cooling by comparing the mixed air temperature and the cooled air temperature. NOTE: The dew point condition from the mixed air to the cooled air condition will be the same if dehumidification is unnecessary.
2. Degrees of work performed for sensible heating by comparing the cooled air temperature with the heated air temperature.

The total of 1 and 2 is total degrees of work spent on the dehumidification operation (A). Next examine:

3. Degrees of work it would take to get from the mixed air temperature to the heated air temperature (B).

The difference between (A) and (B) is the amount of unnecessary work performed.

Insufficient Dehumidification

Finding the optimal preservation condition is equally as significant as optimizing energy performance. In some cases, systems (especially those using chilled water for cooling) may have greater built-in capacity for dehumidification that is typically used, based largely on the incoming chilled water temperature. Working to utilize the full capability of the available chilled water temperature, whether through operational adjustments or, if necessary, component changes such as cooling coil replacement, can have significant impacts on long-term preservation quality. When taken on as part of an overall sustainable preservation program, the increased costs of improved dehumidification can often be offset by energy-savings gained through other strategies.

Excess Energy Loads

Excess energy loads in air-handling zones are common; people, lights, computers, and other components all impart heat to the spaces they occupy. Exterior walls or roof exposure may add heat through solar gain during certain times of the day. While energy loads are to be expected, there are a number of reduction strategies and opportunities available, from both operational and workflow perspectives.

Strive to separate work spaces from storage spaces as much as possible – increased energy loads due to computers, office equipment, and lighting generally come with occupancy. Keeping the missions and zones separate can reduce some of this load, as can following standard practice of keeping doors between differently conditioned spaces closed.

Lighting is a significant electrical load, and non-LED fixtures will emit heat that must be managed by mechanical systems. Light reduction strategies may be appropriate for any space that has poor lighting control (such as a lack of zone control or lighting remaining on during unoccupied periods) or simply excessive lamping for the work performed in the space.

Excessive Time of Operation

Running mechanical systems constantly can be unnecessary and costly, as many spaces can hold their conditions appropriately for at least short periods of time. Experimentation can demonstrate the length and timing of setbacks and shutdowns that is acceptable for each space. While experimentation for short periods is possible with nearly any system or space, those that show minimal or reduced energy loads during unoccupied or nighttime hours may make particularly good candidates.

Depending on building construction, environmental conditions, and occupancy, shutdowns and setbacks can also be applied during daytime hours as a means of reducing peak energy usage in a zone or building. While appropriate durations are typically shorter to maintain environmental conditions, the energy impact can be even greater than reducing nighttime operation.

Excessive Intensity of Operation

Like constant operation, many systems were originally designed to run at 100% capacity all the time; while energy consciousness has allowed VFD technology to become fairly commonplace, many of the drives are still underutilized compared to their potential. Fan power curves have the benefit of allowing for significant energy savings while still maintaining a high percentage of airflow savings of up to 50% of fan energy are possible while still maintaining upward of 75% total airflow.

Spaces that show minimal energy loads at the current operation may make good candidates for experimentation with adjusted fan speeds, provided a VFD is in place. The goal is to find the lowest necessary fan speed that will still maintain the space condition. Reducing fan speed, and thus air volume, can reduce the work done at every component in the system.

The selection of which optimization strategies to test and experiment with requires input from every member of the environmental management team. The strategies are not a one-size-fits-all technique. The ability to successfully perform a strategy will vary from one facility to another. While some institutions can utilize all of the strategies, other institutions may only be able to employ one or two. The team should select strategies that will work for their institution.

The environmental management team can customize the selected strategies for their institution as well, and set their own limits for tests, be it using longer or shorter periods of shutdowns, different fan speeds, or different set point conditions. Institutions should test the combination of strategies that seem to work best for them, and adjust to match collections and building needs.

An experimentation phase of approximately two weeks for each individual adjustment is recommended for most of the strategies; this allows the team to record and measure the impact of the change over a period of time that will hopefully include a variety of weather conditions during the season in question. Certain operational adjustments, such as shutdowns and set point changes, may require several days of experimentation before potential impacts to the storage environment can be seen. Shutdowns may cause cumulative temperature gains in spaces, and a system may work for several days to achieve a set point change before the team realizes that it does not have the capacity to do so. During the assessment phase, the team can review the AHU's performance during the test, and decide whether to repeat the experiment with different parameters. The final results of the test will determine which strategies are implemented and which are abandoned.

The strategies provided in the *Energy-Saving Strategies* section of this methodology are suggestions of common tests and improvements that may work for institutions. Individual organizations may find that specific corrections in sub-optimal operation are necessary, but are not covered in this guide. We encourage you to use the included strategies, evaluation considerations, and testing processes as a template for your own work.

There is no order in which the strategies should be tested. Your team should work together to determine which strategies your equipment and facilities are capable of. After you determine this you should work as a team to decide which strategy to test first. The order of what is tested is completely up to the team.

Evaluation

The final decisions on which strategies to employ will largely be based on the results of the data analysis and the team's review of different strategies. Each potential strategy should be evaluated to determine the appropriateness for the institutional need, chances for success, possible outcomes or issues, and feasibility of implementation. This will help determine which strategies make the most sense to attempt, and in what order of priority they should be tested.

To begin the selection every member of the environmental management team should review the data analysis, focusing on shortcomings in preservation or excessive energy consumption, and consider how different strategies could impact these issues. Team members should comment on the strategies specifically citing any possible concerns they may have or issues they may perceive. Those concerns should then be discussed within the team.

At this stage, the environmental management team should also consider equipment or control limitations, and whether these may eliminate certain strategies.

When analyzing data, the environmental management team may find that there are some optimization strategies already in place; if this occurs, the team should evaluate whether the existing operation is the best possible, or whether additional experimentation may be beneficial. A common example is when facilities are currently employing nightly shutdowns – data analysis should reveal whether the existing shutdown protocol is putting the collections at risk or whether it may be possible to employ longer shutdowns than currently used.

Remember, strategies should not be tested or adopted if they place the collection at risk.

Identifying Potential Risks

Every strategy poses potential risks either to the collection, facility, or the air handling system. In many cases these risks are minor and with some foresight can be avoided or mitigated. It is important to identify and recognize the potential risks of the selected strategies. With careful planning and attention, the team may be able to eliminate risks entirely or at least establish a response plan of action in the event they occur.

Begin by determining the severity of the potential risks, and categorizing them as major, minor, or inconsequential risk. If the consensus is that a risk situation is too great, the test may need to be abandoned or postponed until maintenance or repairs can be performed. For minor risks, establishing a plan of action should a problem occur may be enough to allow the team to continue. The key is to attempt to predict what might go wrong, and be prepared to address and resolve the situation as quickly and orderly as possible. Some teams may choose to put these plans in writing; others may be comfortable with an unwritten team understanding. In either case, the plan of action should be discussed and acknowledged among the entire environmental management team and any additional staff that may need to be involved.

In the event of a critical unseen issue occurring, work to revert to the original operation or control, cease any active experimentation or testing completely, and refrain from further testing until the cause is identified and the issue is resolved.

Know What Areas Are Impacted

It is important to have a holistic view of the entire collection and facility when considering which strategies to experiment with. The team's suggested changes or adjustments are intended to optimize the collection environment, but they may also impact other areas of the facility unexpectedly, whether an office on the same zone or an adjacent exhibition space on a different AHU zone.

Completing the documentation process will provide this insight into much of the facility. By using the documentation to know how your building is connected and how the systems operate, the team can determine what zones or areas of the facility will be directly impacted by an experiment, and what additional spaces or rooms could be affected.

Know the Collection

Before any experimentation is conducted, collections staff should be sure to review among the team any particular environmental concerns or risks for the materials housed in the testing zone, and testing parameters should be defined accordingly. IPI's Dew Point Calculator (www.dpcalc.org) can help plan environmental changes for experimentation by showing the potential preservation impact of altered conditions. Remember to always check dew point conditions – cooler temperatures may be achievable, but without adequate dehumidification, they may cause RH conditions to rise and place certain materials at increased risk for degradation.

Risks to the Collection

There is a common tendency to think about risks as specifically environmental issues – spikes in or loss of control of temperature or relative humidity. However, other physical risks exist that are primarily a function of making an improvement or conducting an experiment. The environmental management team should work to consider the broad range of potential risk during any experimentation or implementation of optimization strategies.

Lighting upgrades is one example. If your facility is working on the replacement of fluorescent lights with LEDs, consider:

- To change the bulbs, the maintenance staff will need to access the collections space. This may involve collections staff having to move collection materials to access lights and having maintenance staff working in the space for extended periods. Be sure to plan accordingly for access and security, and to give proper notice to collection managers in the area in case there are special handling or protection considerations.
- The change from the older style light bulbs (fluorescent, halogen, incandescent), to LEDs may have a potential impact of the temperature in a space depending on the number of fixtures adjusted, style of bulbs, and typical operation. Watch environmental data carefully – depending on how the system is controlled, spaces may become cooler quickly due to the reduction in energy load.

In some cases, risks may not be as significant as initially perceived. Shutting the air handling system down for periods of time (ranging from a matter of hours to unoccupied weekends) will likely lead to some degree of fluctuation in temperature and relative humidity in the space. If managed properly, these fluctuations should be small and only last as long as the shutdown period. Sometimes, however, greater fluctuation may be seen in hot weather or with experimental complications (such as an outside air duct remaining open rather than closing during the shutdown schedule).

The impact of fluctuation on individual objects will vary based on their housing and the amount of surface area exposed. Individual photographs or pieces of paper will equilibrate to environmental changes more quickly than bound volumes or boxed archival collections. Before responding to or correcting for brief environmental changes, consider how long the collection was exposed to the most extreme condition, and whether the material will have felt the full effect of the change. Before abandoning optimization testing, consider whether the risk could be mitigated with different housing or physical control for unprotected materials.

Risks to the Facility

Whenever adjustments are being made to the environment inside a building, it is also important to assess the risks that may be posed to the facility overall. Just as with collection risks, the likelihood for some of these incidents to occur is small, but thinking about them ahead of time and preparing and planning for them can have a major impact in limiting the effects. Every facility is different; it is nearly impossible to predict what to expect with each strategy in every space. However, it is important for the team to consider impacts to staff comfort in addition to the impacts on collections.

One common issue that can occur during the testing of overnight shutdowns – depending on when the system is restarted – is spaces may not return to normal temperature conditions before staff arrive. Conditions that are warmer or cooler than normal may lead to comfort complaints and poor reactions to the testing protocol. Not only is it critical to ensure that all staff are informed of the testing protocol, but another consideration may be making sure that the system will start back up early enough in the morning to recover whatever temperature change occurred. If part of the experimentation is altered set points, be sure to review the purpose of the test with the staff and encourage them to dress accordingly for the new set point conditions.

If the facility is employing fan speed reductions, staff may notice slower air velocity or comment on the "still" air. As with the above example, it is important to inform staff of the purpose of testing and make sure that they understand that the adjustments do not affect the quality of the air.

In both examples, encourage staff to serve as an initial response mechanism, notifying the team if a space has not recovered its set point by mid-morning, or if there is no air coming from a diffuser. Simple tools such as a bit of tissue or lightweight paper taped to a supply air diffuser can help both the team and the staff watch for changes in supply air delivery.

Stakeholders

Once you have identified the area or zone that the experiments will focus on, the team should identify the key stakeholders, if any, for those locations. These may be collections or facilities staff, or other individuals in some way responsible for the collection, zone, AHU, or building in question. In some cases they may already be part of the environmental management team, and will need to inform their own staff of the experimentation process.

It is critical, as much as is possible, to have staff be your allies in the optimization process. This may necessitate a larger group meeting or presentation to explain the process to the larger staff, ask for their assistance in keeping an eye on conditions during the tests, and work with them to find appropriate solutions to any problems that changing environmental conditions may cause, whether comfort related or otherwise. Hopefully, informing the staff and seeking their assistance will help eliminate potential environmental complaints. Another helpful step is to identify a point person to contact – this may be the environmental management team leader, or another staff member – if there are any issues with comfort as a result of the experimentation. Likewise, it is important to keep any technicians who may service the system informed as well – these individuals may not be based in the collections building or zone, but may be housed in other departments across the institution. Again, it is helpful to establish a clear line of communication to ensure that environmental complaints are not immediately acted on, ruining the experiment, without communication with the environmental management team. Certain tests or experiments could cause alarms in a BMS that alert technicians to automatically work to correct, so work to ensure that appropriate staff across the organization are aware of the testing process.

Know Your Equipment

Once inefficiencies or sub-optimal operation have been identified through data analysis, revisit the documentation (building drawings, zone maps, etc.) to confirm which AHU the team is working with. Most optimization strategies pertain in some way to the AHU; it is critical to know as much as possible about its capacity and operation before considering experimentation. The question to consider when evaluating any potential optimization strategy is what the AHU is capable of and whether you have the appropriate equipment and control to conduct the experiment. For example, shutdowns will be difficult to test without a BMS that automatically controls the operating schedule, and fan slowdowns and air-volume adjustments are difficult to perform without a Variable Frequency Drive (VFD).

Risks to the Mechanical Equipment

Whenever adjustments are being made to the air handling equipment there is a risk of potential malfunction or loss of control, some of which can be prepared for, and some of which may just be normal mechanical failure. Considering potential issues ahead of time – have there been control issues in the past, or is a particular piece of equipment near failure already – can help determine whether an experiment should be conducted or if there is a way to minimize any potential issues.

Again, every facility and system is different; it is nearly impossible to predict every potential issue that may arise from individual tests and experiments. Problems may range from control issues of incorrect programming, complete shutdowns or lockouts, or mechanical or control failure of individual components. All these issues that are common enough in normal practice, but that may be exacerbated by purposeful testing.

As mentioned above, the key is clear communication with collections and facilities staff who normally work in the spaces or with the unit. If staff are aware of an experimental shutdown schedule and realize that no air is moving, or the system is still shut off outside of the proposed test schedule, they may be able to catch an issue that may not otherwise show up until the team pulls data a week later. Control issues may be fairly easy to correct, whereas equipment problems may require repair or replacement and necessitate the postponement of the test. Make sure that as experiments are begun, members of the environmental management team or other staff are observing the space and the system to catch any problems as quickly as possible.

The BMS is often another ally in risk management for a system and equipment. Appropriate alarms for unscheduled shutdowns, inappropriate pressure readings or temperature conditions outside of the reasonable set point range can all alert staff and the team to issues that may not be caught downstream until the data pull. Again, be sure that controls staff and contractors are clear on the experimental protocols – which may include providing a written description of what the test is, and what it hopes to accomplish – so that they understand what operational variation is expected and what may indicate a problem. Another potential risk for the system may not occur at the unit at all, but at the BMS system.

It is critical to note that experimentation does not automatically put the AHU or the building at risk – many institutions will never experience issues beyond normal repair, equipment replacement, or preventive maintenance. If the capability is there to slow down the fan speed, modulate a damper, conduct a soft start or stop on a motor, or adjust a valve or water flow, do not be afraid to use it. These are all moving parts that are meant to be controlled – just because they have been performing the same operation without any alteration for years does not mean that they are not capable of safe adjustment. Numerous shutdown tests and schedules have been implemented by IPI and other institutions with no additional equipment attrition (belts, bearings, motors) beyond normal issues or replacement schedules. More often, data analysis and experimentation tend to reveal which components are already malfunctioning, have lost some of their capacity or capability, or may be due for replacement.

Potential Gains

Many of the gains or improvements that can be made by employing optimization strategies can be estimated beforehand through preservation and operational data analysis. The best strategies will yield an improvement in the preservation environment while also providing significant energy savings. Reducing set point temperatures during cool seasons employs passive strategies utilizing cool temperatures on the exterior or surrounding environment to reduce energy consumption while providing a better preservation environment. The cooler temperatures, especially when accompanied by low exterior dew points, can help improve the preservation environment while the reduced heating operation saves energy. If the space would normally be humidifying during the same season, dropping temperature can also help keep the RH higher, reducing energy consumption at the humidifier. Changing lights in a collection space may not only save energy but, depending on the bulbs being replaced, will expose the collection to less UV light, reducing the risk of light damage to exposed materials in the environment.

By utilizing the degrees of work method described in the data analysis section, the environmental management team can also estimate which optimization experiments may be the most beneficial to energy savings. The key is to not become so focused on trying to save energy that strategies that may achieve the larger goal – an optimal preservation environment – are set aside.

When evaluating the potential of various opportunities or strategies, be sure to consider the relative merits of each approach. Lighting upgrades may seem like an obvious option for sustainable operation, but that upgrade takes an initial investment, and the savings and preservation benefit may be relatively small (although it will grow over time) depending on the time of operation and the amount of collection that is exposed. Compare that to a reduction in air volume (fan speed adjustment). If the appropriate equipment – a VFD – is already in place, then the investment in experimentation is very small, simply the labor of making a straightforward control change. If the experiment is successful (safe for the collection and achieves the goal), the benefit may be immediate and at minimal to no initial investment.

These two strategies are both excellent ways to save energy but they only provide small gains to preservation. Other options, such as shutdowns in cool environments or seasons, may yield significant energy savings while also improving the preservation environment, either to a small extent as temperature drops during the shutdown period, or to a larger extent if the shutdown is combined with a cooler temperature set point than initially held.

The environmental management team should be pursuing experimentation that achieves the best combination of:

- Addressing preservation risks identified in the data analysis phase;
- improving on sub-optimal or inefficient operation; and
- feasibility with the existing mechanical system.

Design Experiment

When testing any of the strategies included in this methodology it is important to follow the guidelines. Most of the strategies included follow a similar testing and execution plan. If data analysis shows opportunities for improved operation that are not covered here, use the included strategies as templates for process and design. Below are a few additional guidelines for how to approach your own experiment:

1. Have your data software established. If you are using an eCNB account, be sure that the account is activated, set up, and that you have some experience using it. To perform proper data analysis, it is important to have the appropriate software and the ability to use it with the team.

2. Install enough dataloggers to monitor the experiment in both the space and the system.

    a. During an experiment, data from the dataloggers should be pulled at least once a week. The management team should meet to analyze the data to assess and evaluate the test.

3. Have a response plan for any major issues that might arise.

4. For strategies that require implementing an operation schedule, be sure that the schedule has been agreed upon by all members of the environmental management team and has been communicated to appropriate collections and facilities staff.
5. For strategies that employ any set point changes to the temperature or RH within a space be sure to review the proposed conditions with the Dew Point Calculator website. This is the best way to compare the temperature, RH, and dew point for the space with the potential value or risk to the collection that these set point changes may pose.
6. A testing period should be a minimum of two weeks. If the experiment shows successful results after the initial test, the team can consider whether to adopt it as part of a long-term operational strategy.
   a. Due to seasonal effects on the environment, strategies like shutdowns and setbacks should have separate winter and summer tests performed to establish the desired operation for those seasons.
7. Within your environmental management team identify the point people for the experiment.
   a. Who will any complaints, issues, or emergencies be directed to?
   b. Who will perform the data pulls?
   c. Who will check on the equipment and controls?
   d. Who will inspect the spaces?
   e. Who will be responsible for documenting the experimental process and data?
8. Properly inform all who may be affected by the experiment – what the test is, why it is being performed, what they may expect, and if they have any issues, who to contact.
9. The first day or night of the test assign an individual to verify that the experiment actually started (and/or stopped if on a schedule).
10. Walk the spaces daily during and after the test to ensure there are no issues.
11. Check the controls, and ideally the equipment, daily during the test to ensure everything is working properly.
12. Pull and analyze data weekly during the testing period.
13. At the end of the test, inform all parties that the test has concluded.
14. Update the BMS to new settings or return to the former programming.
15. If no further data gathering or experimentation is required, remove all dataloggers from the mechanical system.

Strategies deemed successful after experimentation and assessment may be worth exploring in other parts of the building, with similar systems, or elsewhere in the facility or campus.

METHODOLOGY:
ASSESSMENT & MAINTENANCE

The assessment phase is in many ways quite similar to data analysis – the goal is to analyze and assess the impacts of experimentation. The key difference is that the purpose of the experimentation data analysis is to determine which strategies or operational adjustments will be kept as part of the overall sustainable preservation strategy, and which ones either need further experimentation or are deemed inappropriate for the preservation environment and/or the system.

Assessment seeks to answer three critical questions concerning the experiment in question:

- Did it accomplish the desired operational or environmental change without putting the collection at risk?
- What is the quantified difference between the original operation and the experimental result?
- Is that difference significant enough to maintain the new operation, or would it benefit from further experimentation?

Each of these builds on the previous. Failure to accomplish the goal, or putting the collection at risk, may mean that the strategy is abandoned or requires further testing. Experimentation and assessment can become a repetitive loop of the optimization process – take the following example:

- Institution A decides to experiment with controlled system shutdowns for ten hours every night in summer, based on occupancy schedules;
- The initial shutdown test fails due to an inability to manage the schedule with the BMS;
- Programming capability is updated, and the shutdown test is repeated;
- The second test shows the shutdown control to be successful, but space temperatures rose by 5°F overnight;
- A third test is conducted using a six-hour shutdown;
- The shutdown control is successful, and space temperatures only varied by 2°F.
- Part of the team is satisfied with the gain, and wants to implement and maintain. Part of the team wants to test an 8-hour shutdown. The 6-hour shutdown is implemented for summer months.
- At the beginning of the winter season, a new test is conducted for a 10-hour time period.

While this is extreme, it illustrates the fact that experimentation can be taken as far as the environmental management team wants to pursue the strategic opportunity. What allows the process to remain practical is that assessment is often much easier than the original data analysis – as long as the team is only experimenting with one operational variable at a time, cause and effect are fairly easy to determine.

Quantification during the assessment phase is critical – it allows the team to communicate their activities in terms that other parts of the organization can appreciate or value. Being able to communicate the impact on both preservation and energy is necessary; achieving an optimal preservation environment means working toward achieving the balanced goals of the best possible preservation at the least possible energy consumption.

Quantifying the preservation impact can happen in various ways. The team may choose to define it by reduction of risk – for example, original RH conditions above 70%, which placed the collection at risk for mold germination, have been corrected and RH is now maintained at 60% or less. Another option is using the IPI's Preservation Metrics, especially when looking at long-term chemical decay. Using Time-Weighted Preservation Index (TWPI) as an indicator can be difficult as it takes into account the entire history of data, and a short-term test (or even an entire year) may not be enough to significantly alter the TWPI metric. However, when quantifying the impact of the change, it is often helpful to compare the relative Preservation Index (PI) of the original versus the adjusted set point conditions. Take this example:

- Original winter set points:
    - 72°F/50% RH PI: 34
- Tested new winter set points:
    - 65°F/35% RH PI: 85
- Increase in seasonal preservation quality: 150%.

Teams may also choose to compare the test performance against a previous period, say the test period versus the same calendar dates from the previous year. The key is understanding that, while the numbers will never be entirely accurate – environments rarely stay at precisely the set point condition, and year-to-year operation can vary significantly – the metrics nonetheless give a sense of the scale of improvement, which is valuable for planning and assessment.

There are also various methods for quantifying energy impact. The simplest may be working with the degrees of work method described in the data analysis section – totaling and comparing the degrees of work performed by a particular operational process before and after the test and expressing the impact as the percentage of work saved. Additional numbers may also be available, depending on the building and the size of the AHU being experimented with, the energy impact of the test may be great enough to show up in the energy meter readings often maintained by the facilities department. Institutions may also pursue actual energy calculations based on altered energy usage at various components. Degrees of work, volumes of air worked on, and amperage consumption over time can be converted to total BTUs, tons of cooling, and kilowatt-hours respectively. Once actual energy rates are known, energy-savings may be converted to actual dollars.

Be aware of how you communicate the potential impact of the altered operation. A common disappointment among energy managers and environmental management teams is that projected monetary impact – especially when experimenting with small AHUs – can be relatively minor, sometimes no more than a few thousand dollars a year, depending on the strategies tested. Depending on the institution, this may either seem like an excellent outcome, or a disappointing result for the amount of effort involved. In practice, and with the goal of sustainable preservation in mind, it is often more useful to express any achievements in terms of percentages. A 40% reduction in energy consumption at the primary AHU that serves the collections environment is a sustainability success regardless of the actual monetary amount, and the environmental management team should take satisfaction from contributing to the overall sustainability goal of the institution.

Assessment of the experiment is only accurate for the time frame in which the test was conducted. For many strategies, including shutdowns, fan speed alterations, and seasonal set point changes, tests will likely need to be conducted seasonally to determine the appropriate operation during hot, cold, humid, or dry weather conditions.

In many cases, once the experiment is conducted for a season, and assessment has confirmed appropriate operation, that control can be repeated from one year to the next, unless mechanical upgrades or architectural renovations occur.

If data review and assessment have shown a particular experiment to be successful, the environmental management team should determine whether the new strategy should become part of the permanent operation of the AHU and space. Optimization is in many ways a cumulative process – successful strategies are adopted, and subsequent tests are performed with the new operation in place. If the strategy is to be kept, two critical actions need to be taken:

- Communicate with the facilities, controls staff, or controls contractors to implement the new operation into the programmed control sequence of the AHU in question.
- If there is a written, plain-language sequence of operation – whether in the original mechanical drawings, in the BMS, or some other source – work with facilities staff to update the sequence of operation record immediately, noting what the changes were and when they were implemented.

Many successful strategies and experiments have been lost operationally because they were never properly documented in the sequence of operation or controls programming. If not documented, subsequent controls upgrades, recommissioning studies, or other efforts may revert the operation of the unit back to a previous or original sequence of operation, without implementing the new strategies.

Once a strategy has been implemented into the permanent sequence of operation, the environmental management team may choose to pursue another improvement or strategy, whether for improvement of preservation or energy purposes (while maintaining preservation quality). That next strategy should be tested with the previously adopted strategy in place – for example, if the team settled on an appropriate shutdown protocol, new experimentation with adjusted fan speeds should be conducted with the shutdown in place. In rare cases, the team may choose to alter a previously adopted strategy in order to accommodate a new test, but generally it is best to build on successful operation.

As discussed in *IPI's Guide to Sustainable Preservation Practices for Managing Storage Environments*, optimization and sustainable preservation are long-term processes, not single-time projects. The formation of an environmental management team should be considered a permanent commitment on the part of the institution, even if its members change over time. Building and mechanical operations also rarely remain exactly the same over time – small building or system adjustments, aging of equipment, and new staff and ideas can all translate to undocumented altered behavior over time. An experiment and operation that was successfully implemented five years ago may easily be lost or changed over time. The long-term role of the environmental management team is to be involved in continuing discussions about system and space upgrades, the implementation of new preservation guidelines based on research, and striving to maintain optimal operation for preservation and energy. This maintenance mode should include ongoing data analysis of collections environments, regular review of AHU controls and set points, periodic analysis of mechanical operation – especially if environmental conditions or energy usage are seen to change – and, as necessary, periodic retesting of various strategies. With the environmental management team in place, institutions should be well-positioned to take these changes in stride, analyzing the impacts, responding appropriately, and experimenting with new operational strategies where necessary.

ENERGY-SAVING STRATEGIES:
SYSTEM SHUTDOWNS

Goal: To use risk-managed mechanical system shutdowns to achieve significant energy savings while minimizing the impact on the preservation environment.

Advantages	Disadvantages
Best possible energy savings	Potential for significant fluctuation in poorly insulated buildings
Often simple mechanical control	Potential for mechanical failure
Can have minimal impact on environmental conditions	Potential difficulty recovering to set point the next day

Description of Potential

Mechanical system shutdowns have been used for decades as a key strategy in energy-reduction initiatives in public and commercial buildings. Turning mechanical systems off during unoccupied hours (typically nighttime) takes advantage of the lack of need to condition for human comfort as well as the reality that the best potential energy savings on mechanical operation comes from not running the equipment at all.

This strategy has particularly strong potential in collection storage areas, where human occupancy is less of a concern. The potential viability of system shutdowns can be gauged by how well the system zone or physical space can hold its appropriate conditions without mechanical intervention. In well-insulated storage facilities, shutdowns may even be appropriate for periods during daytime hours, when summer heat loads are at their greatest. For institutions who pay peak rate charges on energy during those hours, daytime shutdowns may be a significant opportunity.

In the simplest definition, a system "shutdown" means turning off power to the fan units that circulate air through the AHU and the zone/spaces. Ideally, the various components that impact air conditions within the unit will also close or open appropriately. Outside air dampers should typically close in order to prevent unconditioned air from entering the building, a pre-heat coil may activate in cold seasons/climates (but not in warm seasons) to protect against frozen heating or cooling coils, primary heating or cooling coils may valve closed to avoid unnecessary circulation of steam/water, and other electrical components – heating coils, electrical filters, etc. – will also power down to save energy. All of this depends on the particular design and arrangement of your mechanical system. By using dataloggers or BMS data from an AHU, it is possible to examine data during a shutdown period and determine what components may remain running or open.

Potential energy savings from AHU shutdowns are often a factor of the percentage of a 24-hour period that a unit is turned off. If an institution is able to conduct an 8-hour nightly shutdown, then yearly savings of 33% may be possible; even a 3-hour shutdown can see 12% savings. A number of factors can influence actual realized savings, including time, peak rate charges, and type of equipment being used (constant volume vs. variable speed fans, direct expansion cooling vs. chilled water, etc.), and may reduce that total savings percentage. The energy impact of shutdowns in collections areas is often best quantified or compared as a percentage of energy used on the "air-side" (the air handler and the associated building zone) of the system. Impact on the "water-side" (boilers, chillers, etc.) is often minimal, especially when specific AHU(s) are a small customer on the overall building, district, or central plant steam, hot water, or chilled water system.

Although improvements in the preservation quality of the environment are theoretically possible during certain outdoor conditions (primarily cooler, drier weather), in practice they are rarely achieved due to the relatively short duration of most operational shutdown periods in occupied spaces.

Requirements

- Automated control of mechanical system is preferable
- Ability to schedule system operation
- Identified zones served by the AHU to be shut down
- Data logging within the mechanical system (if quantified energy savings are desired)
- Data logging in the collection space (to monitor the storage environment for any potential risk)

Critical Data Points

- Preservation
    - Space data from each space affected by the system that is shut down
    - Identification and monitoring of potential microclimate areas that may fluctuate differently than the rest of the space (especially near doors, windows, or anywhere that outside air may infiltrate)
- Energy
    - Data from each location in the system where a component can mechanically work on the air:
        - Return air
        - Mixed air
        - Pre-heated air
        - Cooled air
        - Heated/supply air
        - Fan amps
        - Downstream reheats
        - Others (as needed)

Pre-Testing

- Be certain that outside air dampers fail closed upon shutdown
- Be wary of coils that may fail open, especially heating coils – while this control is fine, make sure that the heat cannot transfer downstream (i.e., via an open outside air damper)

System Notes – DX Cooling Systems

- There is a tendency to save less energy than with chilled water coil systems – the DX compressor and coil may run at increased rates on the day following a shutdown in order to catch up with any loss in space conditions, decreasing the total energy saved from the night before.

System Notes – Desiccant Dehumidification Systems

- In certain situations, the exhaust air from the regeneration side of a desiccant system can condense during a system shutdown. Factors that can cause this include:
    - If the desiccant system sits in a conditioned space with a temperature lower than the exhaust air dew point
    - If the exhaust air ductwork on the building interior is not insulated

In these situations it is possible for the condensed moisture on the interior of the ductwork to run back to the desiccant chamber and damage either the wheel or the wheel motor.

Selection Criteria/Variables That Impact Potential

- Outdoor Climate
    - Shutdowns can be more difficult in hot/humid seasons and climates. Locations with outdoor temperatures that remain warmer than interior set points may need to initially test with shorter shutdown periods to mitigate risk.
- Building Envelope
    - The less exterior wall exposure in the collections space, the less likely it is that the space will see large fluctuations
    - The better the thermal and vapor barrier a building has, the less fluctuation will occur
    - Sub-grade spaces are often prime candidates for system shutdowns
- Occupancy
    - The best initial test period is during unoccupied hours
    - In an unoccupied storage area, the shutdown can take place at any time of day
    - If unoccupied hours are limited, aim to shut down no more than 1-2 hours before closing, and turn back on at least 1 hour before opening

    - Be careful of mixed-use zones – unoccupied storage is a plus, but a shared workspace may still need airflow
- Storage Density
    - Higher-density storage (library stacks, high-density storage modules) tends to fluctuate less than large air-volume spaces (such as galleries)
- Space Load
    - Using the method for calculating space loads described in the data analysis section, inspect your baseline data for the supply, return, and space air conditions. The smaller the load in the space, the more likely that a shutdown will be successful in terms of seeing minimal fluctuation. The greater the load, the more fluctuation will likely occur.

Shutdown Experimentation (Test) and Implementation

PREPARATION

- Complete documentation, data gathering, and analysis steps for the system/spaces being calculated.
- Use the selection criteria above to review whether the system/space is a good candidate for shutdown testing.
- Confirm that the system is capable of conducting programmed shutdowns.
- Confirm that appropriate data gathering capabilities are deployed and determine who will pull and check data, and how often. The frequency of data pulls and analysis is up to the institution and is based on staff scheduling and the level of risk management desired for a particular collection space. Common approaches include:
    - A daily walk-through of the space to be sure that normal daytime set points are being held
    - Weekly data pulls from all dataloggers (space and mechanical system locations) to inspect nighttime fluctuation
- Determine test parameters:
    - Night shutdown time
        - In hot/humid climates begin testing with 2-4 hours nightly shutdowns.
        - In temperate climates and seasons begin testing with 6-8 hours nightly. Daytime “peak” shutdowns can be tested in well-insulated buildings, but should be limited to 2-4 hours for initial testing.
        - In cool/cold climates and seasons begin testing with 8 hours nightly. If successful, consider extending the shutdown time to the full length of unoccupied hours.
    - Unoccupied shutdowns
        - Some institutions may want to test shutdowns during the entire time the building or space

is unoccupied, which may include weekends or other multiple day periods. In these situations, it is important to look at the total fluctuation in the space during the entire shutdown period, and the length of time and energy it takes for the system to recover to its original set point.

    - In some cases, systems may not recover to their set point during the "on" period, resulting in cumulative changes (steadily rising temperatures) in space conditions over a long period.

- Length of shutdown test:
    - Typically an initial test should be allowed to run for two weeks. Environments can respond differently based on outdoor weather conditions and two weeks is a reasonable compromise between gathering a representative sample set for a season and limiting any long-term risk.
    - If drastic or concerning fluctuations are experienced during the two week test period, the period of the shutdown should be reduced or the testing halted altogether.
    - Fully optimizing a shutdown will include initial seasonal tests in the extreme seasons to determine any variability in appropriate shutdown capability and lengths.
- Communicate the shutdown plan to collections and facilities staff responsible for managing the areas involved:
    - Discuss the potential impact on human comfort in the space.
    - If the shutdown will occur during work/occupied hours address the possibility of "still air".
    - Discuss how to schedule the restart to best recover to set point before the space is occupied.
    - Propose a start and end date for the test period and make sure that they fit with departmental needs.
    - Set up a communication structure during the test period for any environmental complaints or work-orders associated with the AHU being shut down.
- Finalize a start and end date for the test period

ON TEST START DATE

- Facilities staff should physically confirm that the system actually shuts down during the first shutdown period
- Facilities staff should notify team members and building facilities staff that the testing has begun
- Collections staff should notify other staff members that testing has begun
- Facilities staff should physically confirm that the system starts back up at the scheduled time

DURING THE TEST PERIOD

- Collections staff should conduct daily walk-throughs of test space and check space dataloggers for deviation from set point range
- Follow schedule for data retrieval from space and mechanical systems
- Facilities staff should conduct regular checks of BMS for alterations in system operation
- First data retrieval as per test schedule
    - Look for evidence of shutdowns in data from both the space and mechanical system dataloggers
    - If shutdowns are not occurring according to the planned schedule, work with facilities staff and/or controls technicians to find and resolve the problem
- Evaluate results of test shutdowns
- If the results of the initial test are acceptable, continue the shutdown test protocol until the end date

AT THE END OF THE TEST PERIOD

- Conduct a final walk-through of systems and spaces
- Retrieve and upload data from space and mechanical system dataloggers
- Conduct final analysis of the test data as a team
- Meet with collections and facilities staff that manage the area to discuss any observations on their part during the test period and communicate the results of the final data analysis to them
- If no deviations from normal "on" set point conditions have been recorded, allow the shutdown procedure to continue through to the implementation phase
- Results of analysis will determine the next step:
    - If fluctuation in the space was minimal, consider testing with expanded shutdowns, either in duration or during different parts of the day
    - If test results were not favorable, consider altering the test in some manner (reducing length of shutdown, changing the time of day) to achieve more acceptable results
- If testing of all strategies for that AHU is complete, remove mechanical system dataloggers and reset them to be used in experimentation for other systems
- Compile, quantify, and report test results to appropriate administrative staff

Once a team has determined a shutdown procedure should be adopted, and settled on a schedule, the process enters the implementation/maintenance phase. At this point, the team should be satisfied that they have tested the potential variants of operations and schedules, and have chosen the best operation for the needs of both preservation and energy savings.

Implementation/Maintenance

- Add the final shutdown schedule and operation to the normal sequence of operations for the AHU, both in programming and in any written documentation.
- If using a BMS for system control, note the appropriate operation of the unit while using the shutdown strategy – including confirmation of schedule, valve/damper positions when the unit is off, and any other factors that will help identify whether or not the AHU is functioning as it should for a shutdown.
- Repeat the test procedure seasonally if outdoor climate conditions vary widely (i.e., initial testing in summer may only yield a six-hour shutdown as appropriate, while a winter season may allow for a ten-hour shutdown).
- Collections staff should continue pulling and reviewing space data once a month. Any variation from documented space conditions should be watched and reviewed with the team.
- Review and analyze space data (via dataloggers) and mechanical system operation (via BMS) every 4 to 6 months to ensure that the shutdown protocol remains in place, is of the appropriate length for the season, and that the space response to the shutdown is still appropriate for preservation.
    - If the operation deviates from the intended sequence of control, use the system and space documentation and compare those to the current operation and environmental behavior to try and diagnose the problem
    - Discontinue shutdowns until the problem is resolved
    - Repeat testing procedure as necessary to determine the appropriate operation

Evaluating Test Results

SPACE DATA

- **Temperature** – Look for day/night curves that match the shutdown schedule. Often spaces may fluctuate as little as 0.5°F and up to 4 or 5°F over an 8-hour period.
    - Shutdowns are considered successful if:
        - The fluctuations in temperature are not greater than those seen during normal operations,
        - do not result in relative humidity changes that exceed the safe range for collections,
        - do not rise significantly; and
        - there is no cumulative temperature gain after successive shutdowns.
    - Research shows that temperature equilibration in materials is fairly rapid, with full equilibration to a one-time change occurring within a matter of hours. Keep in mind that with shutdowns, the temperature changes gradually over the shutdown time period and therefore the full amount of change may only be felt for a small portion of the shutdown.

- **Relative Humidity** – Unless a serious moisture incursion significantly raises the dew point, the relative humidity typically does one of two things during a space shutdown – the RH either moves slightly in conjunction with temperature changes, or it remains steady as a result of the collection releasing or taking on moisture due to the ambient temperature change.
    - Research conducted by IPI has shown that the moisture equilibration rates (for full equilibration at the core of an object) for many hygroscopic materials found in libraries and archives are relatively slow, and may take weeks for materials to fully equilibrate to a one-time RH change in the ambient environment. Material surfaces will equilibrate faster and significant RH changes (again, typically due to dew point fluctuation) may cause mechanical change to sensitive media.

- **Dew Point** – Any fluctuations in dew point as a result of the shutdown typically indicate a moisture incursion in the space that is independent of any moisture brought in through outside air intake (assuming that the outside air intake successfully closed during the shutdown). If more than a 1-2°F variation in dew point is observed as part of shutdown testing, team members should inspect the space and building envelope for sources of moisture or outside moisture intrusion.

MECHANICAL SYSTEM DATA

- **Supply Air** – Use the datalogger in the supply air to provide the clearest "air" illustration for confirmation of the shutdown. During operation the system provides conditioned air to spaces downstream, while during the shutdown, the environment recorded inside the supply air duct often reverts to match the ambient condition of the space around it, whether it is the mechanical room or a supply diffuser in the space.
- **Fan Amps** – If an electrical datalogger is used on the power supply to the supply fan motor, the resulting amp usage graphs can also be used to confirm on/off times of the mechanical system, as well as to calculate the energy saved by shutting down the supply fan.

REMINDERS FOR MAXIMIZING EFFECTIVENESS

- In unoccupied spaces/zones, test shutdowns during daytime "peak" hours to reduce the peak load on the energy budget
- In cool/cold climates and seasons, explore expanding shutdowns beyond normal "unoccupied" hours, especially if the space is typically unoccupied

Shutdown Log Sheet for Zone/AHU#

[Organization Name]

Collection Staff:
Facilities Staff:

Is System Capable of Being Shut Down
YES NO
Shutdowns: Auto Manual

Pre Test:
Outside Air Damper Fail: Open Closed
Heating Coil Fail: Open Closed
Cooling Coil Fail: Open Closed
Logger Placement: Mech System Collection Space
Fan Amp Logger: Yes No

Mechanical System Logger Locations:
Outside Air/Preheated Air
Heated Air Supply Air
Cooled Air Downstream Reheat
Return Air Other__________
Mixed Air

2 Week Test

Date	System Stop	System Start	Duration	Recovery Time	Other Changes Made to the System	Notes

Daily Walk-through Log: Check if System and Space are Following Shutdown Schedule

Mon	Tues	Wed	Thurs	Fri	Sat/Sun

Daily Log: Upon Startup Verify That the Space and System Return to Normal Operation

Mon	Tues	Wed	Thurs	Fri	Sat/Sun

Daily Check of the BMS System:

Mon	Tues	Wed	Thurs	Fri	Sat/Sun

Weekly Data Pull

NOTES:

Post Tests:

Did System Shut Down Correctly: Yes No

Did System Start Back Up Properly: Yes No

Did Space Temperature Return to Normal: Yes No

Average Space Temperature Fluctuation: _______

ENERGY-SAVING STRATEGIES: SYSTEM SETBACKS

Goal: To use appropriate, risk-managed mechanical system set point setbacks in temperature or relative humidity to achieve energy savings with minimal impact on the preservation environment.

Advantages	Disadvantages
Often simple mechanical control	Potential to forget to restore equipment to normal operation
Potential to temporarily improve environmental conditions for collections, particularly in modern buildings	Decreases in temperature may increase human comfort complaints
Fluctuations in temperature or RH should be short in duration and have little effect on collection materials	
Cumulative energy savings over time	

Description of Potential

Many institutions that would like to implement HVAC system shutdowns find that they are not capable of doing so for various reasons. Though these facilities cannot take advantage of shutdowns they can often explore implementing nightly setbacks in temperature and RH. These nightly setbacks do not produce the same energy savings that shutdowns can, but they still allow the facilities to reduce use of the HVAC system and potentially take advantage of seasonal conditions that may temporarily help produce a better environment and save some energy when the facility is unoccupied.

Setbacks are defined as methodical nightly, weekend, or seasonal adjustments to HVAC settings. This strategy deals specifically with setbacks in temperature and relative humidity set points. It is NOT recommended that institutions experiment with setbacks in summer dehumidification/dew point control. The intention of setbacks is to use less heating or cooling during unoccupied hours when human comfort is not a concern, similar to adjusting a home thermostat when the house is unoccupied or the occupants are asleep. The use of setbacks does not involve using more outside air or economizing more to get a different condition. The setbacks in temperature and relative humidity set points are programmed into the mechanical system and typically tied to the occupied hours of the facility. During the unoccupied hours the system initiates the lower set points. The system should hold these set points for the period of time that the facility is unoccupied and return to the normal set points just before staff arrive.

The use of setbacks does not involve simply turning the temperature in a space down as low as possible. As the temperature of a space is lowered, if the dew point remains constant, the relative humidity will rise. If the temperature in a space is lowered too much there could be significant issues associated with the higher humidity, such as condensation on walls or windows, or mechanical damage to vulnerable, exposed collections in the space. Before setbacks are programmed the average dew point control for the AHU zone must be known. Inputting a dew point into Dew Point Calculator (www.dpcalc.org) allows for the determination of how low the space temperature can drop and still maintain safe RH levels.

Most setback experiments will focus on temperature, especially if a facility is already using different seasonal set points and maintaining seasonal upper and lower limits in RH. The experimental goal is to allow the condition of the space to alter slightly while still providing the same quantity of airflow. In cold environments/seasons, one example might be dropping the temperature set point from 68°F to 64°F during unoccupied hours, reducing the amount of heating performed while slightly improving the preservation environment for the unoccupied period.

RH setbacks are typically only feasible if the AHU zone is currently maintaining a mid-range (40-50%) constant RH control in dry environments/seasons. In these situations, an institution may experiment with a short-term RH setback down to 30-35% as a means of saving energy at the humidifier while maintaining safe conditions for most materials. However, if the collection is tolerant of 30-35% RH conditions, most facilities will be better off experimenting with and implementing a full seasonal set point change to those RH levels, rather than only using an unoccupied setback setting.

Summer setback testing must be carefully considered before experimentation. AHUs that are dehumidifying via subcool and reheat WILL NOT see an energy benefit from rises in space temperature during unoccupied hours. Due to the nature of the subcool/reheat process, raising temperature set points during unoccupied hours will actually result in increased energy use at the reheat coil, while slightly reducing the preservation quality of the zone. Summer temperature setbacks with other system designs – desiccant dehumidifiers and sensible cooling controls – have greater potential for success with minimal collection risk.

Experimentation with temperature setbacks should always take the potential impact in relative humidity levels into consideration. A separate two week testing period is recommended for each season to verify if the setbacks will work in that facility with the collection. Pre-testing is described later in this document.

Requirements

- Automated control of mechanical system is preferable
- Ability to program system operation
- Knowledge of temperature and RH limits based on vulnerable collection materials
- Knowledge of hours of operation and/or work schedule for the AHU zone
- Data logging within the mechanical system (if you want to quantify energy savings)
- Data logging in the collection space (to monitor the storage environment for any potential risk)

Critical Data Points

- Preservation

        - Space data from each space affected by the system during the setbacks
        - Identification and monitoring of potential microclimate areas that may fluctuate differently than the rest of the space (especially near doors, windows, or anywhere that outside air may infiltrate)

- Energy
    - Data from each location in the system where a component can mechanically work on the air:
        - Return air
        - Mixed air
        - Pre-heated air
        - Cooled air
        - Heated/supply air
        - Fan amps
        - Downstream reheats
        - Others (as needed)

Pre-Testing

- Use Dew Point Calculator (www.dpcalc.org) to evaluate the temperature and relative humidity conditions you intend to use
    - Analyze dew point graphs for the selected space over time in eClimateNotebook® (www.eClimateNotebook.com) to determine the expected dew point. Use this dew point with the selected temperature to find the potential relative humidity for the space.
- Verify the hours of operation and staff work schedule for the facility
- Notify all staff of after-hours temperature adjustments

System Notes

- Be sure to set start and end dates if the use of seasonal setbacks is necessary
    - One helpful method may be to look at your outdoor data in eClimateNotebook® (www.eClimateNotebook.com) and identify the seasonal transition points
- Verify the type of system that serves your space
    - If the AHU operates as a subcool/reheat arrangement, be careful of the misconception that turning the temperature up in the summertime in a space means you are using less energy. With sub-cool and reheat systems, turning the heat up in the summer will use more energy.

Selection Criteria/Variables That Impact Potential

- Outdoor Climate
    - Take advantage of cooler outside temperatures by employing passive methods to let the space temperature drop naturally
- Building Envelope
    - Infiltration of outside air near doors, windows, open plenum returns, stairwells, etc. may produce microclimates causing the temperature in some areas to drop lower than desired and could impact the relative humidity levels
- Occupancy
    - Staff who work after hours may have comfort complaints due to the different temperatures in a space
    - Communicate the experimental process clearly to all staff in the AHU zone to be tested
        - Complaints to facility managers may result in unforeseen adjustments
        - Test results may be skewed if facility mangers or staff members alter space temperatures due to comfort complaints
- Space Load
    - Ensure that staff are not using independent space heaters that can be left on and may provide false readings or add extra heat to the space
- Power
    - Verify that in the event of a power outage, system operation is restored and the system is working properly

Setback Experimentation (Test) and Implementation

PREPARATION

- Complete documentation, data gathering, and analysis steps for the system/spaces in being evaluated
- Use the selection criteria above to review whether the system/space is a good candidate for setback testing
- Confirm that appropriate data gathering capabilities are deployed, determine who will pull and check data, and how often. The frequency of data pulls and analysis is up to the institution and is based on staff scheduling and the level of risk management desired for a particular collection space. Common approaches include:
    - A daily walk-through of the space to be sure that set points are being held

            - Weekly data pulls from loggers to analyze data
- Determine test parameters
    - Occupied space setbacks
        - Avoid testing setbacks during occupied hours.
        - Occupied spaces are limited in the amount of temperature setback possibilities due to use. Set points should be selected that consider human comfort as well as collection risks.
    - Unoccupied space seasonal set point changes
        - Unoccupied spaces benefit from the ability to lower the temperature significantly compared to occupied spaces. When evaluating unoccupied spaces, the most significant factor may be the relative humidity level.
        - Be sure that the temperature you are using produces a safe relative humidity.
    - Length of setback test
        - Set a start and end date for the test period.
        - The set points for a setback can be introduced at any time of the year. However, separate setback set points may be needed for the winter and the summer seasons
        - Typically an initial test should be allowed to run for two weeks. Environments can respond differently based on outdoor weather conditions and two weeks is a reasonable compromise between gathering a representative sample set for a season and limiting any long-term risk.
- Communicate the setback changes to collections and facilities staff responsible for managing the areas involved.
    - Discuss the potential impact on human comfort in the space
        - If the setbacks will occur in occupied spaces be sure all staff are aware of the changes and that they can plan accordingly
        - Be sure staff do not use alternative methods of heating during the testing period
        - Set up a communication structure during the test period for any environmental complaints or work-orders associated with comfort or temperature complaints
    - Finalize start and end date for the test period and make sure that they fit with departmental needs

ON THE TEST START DATE

- Facilities staff should physically confirm that the system has switched over to the setback set points
- Facilities staff should notify team members on the day that the testing starts
- Collections staff should notify other staff members on the day that the testing starts

DURING THE TEST PERIOD

- Facilities staff should be sure to forward any comfort complaint calls to the facilities team representative
- Collections staff should conduct daily walk-throughs of test space and check space dataloggers for deviation from set point range.
- Follow schedule for data retrieval from space and mechanical systems
- Facilities staff should conduct regular checks of BMS for alterations in system operation
- First data retrieval as per test schedule
    - Look for evidence of setbacks in data from both the space and mechanical system dataloggers
        - If setbacks do not appear to be employed, work with facilities staff and/or controls technicians to find and resolve the problem
    - Evaluate results of test setbacks
- If the results of the initial test are acceptable, continue the setback test protocol until the end date

AT THE END OF THE TEST PERIOD

- Conduct a final walk-through of systems and spaces
- Retrieve and upload data from space and mechanical system dataloggers
- Conduct final analysis of the test data as a team
- Meet with collections and facilities staff that manage the area to discuss any observations on their part during the test period and communicate the results of the final data analysis to them
- Results of analysis will determine the next step:
    - If test results were favorable
        - Continue using the conditions through the season
        - Consider testing with cooler conditions
    - If test results were not favorable
        - Consider altering the test in some manner (raising/lowering the desired temperature) to achieve more acceptable results
- If testing of all strategies for that AHU is complete, remove mechanical system dataloggers and reset them to be used in experimentation for other systems
- Compile, quantify, and report test results to appropriate administrative staff

Once a team has determined a setback, procedure should be adopted on a schedule to follow, and the set points to use, the process enters the implementation/maintenance phase. At this point, the team should be satisfied that they have tested the potential variants of temperature and relative humidity set points allowable, and have chosen the best operation for the needs of both preservation and energy savings.

Implementation/Maintenance

- If the team has determined that using setbacks is desirable be sure to agree on solid start and end dates for the use of seasonal setbacks before implementation
- If possible, add setbacks to the schedule for the AHU, both in programming and in any written documentation
- Be sure to add setback changes to the facility calendar and the collections calendar as a reminder to verify the implementation of winter setback set points and return to summer setbacks set points

Evaluating Test Results

SPACE DATA

- **Temperature** – Look for day/night curves that match the setback schedule. Changes should match the designed setback set points and schedule.
- **Relative Humidity** – Unless a serious moisture incursion significantly raises the dew point, the relative humidity typically does one of two things during the setback – the RH either moves slightly, inversed to temperature changes, or it remains steady as a result of the collection releasing or taking on moisture due to the ambient temperature change.
    - Research conducted by IPI has shown that the moisture equilibration rates (for full equilibration at the core of an object) for many hygroscopic materials found in libraries and archives are relatively slow, and may take weeks for materials to fully equilibrate to a one-time RH change in the ambient environment. Material surfaces will equilibrate faster and significant RH changes (again, typically due to dew point fluctuation) may cause mechanical change to sensitive media.
- **Dew Point** – Any fluctuations in dew point as a result of the setback typically indicate a moisture incursion in the space that is independent of any moisture brought in through the outside air intakes (assuming that the outside air intake successfully closes during the setback). If more than a 1-2°F variation in dew point is observed as part of the testing, team members should inspect the space and building envelope for sources of moisture or outside moisture intrusion.

MECHANICAL SYSTEM DATA

- **Supply Air** – Use the datalogger in the supply air to provide the clearest "air" illustration for confirmation of the setbacks. During normal operation, the system provides conditioned air to spaces downstream, while during setbacks, the condition of supply air should alter either warmer or cooler depending on the experimental set point.

REMINDERS FOR MAXIMIZING EFFECTIVENESS

Be sure to fully inform staff:

- Not to adjust the temperature due to comfort issues in occupied spaces
- To dress for lower temperatures in unoccupied spaces

System Setback Sheet for Zone/AHU#

[Organization Name]

Collection Staff:

Facilities Staff:

Logger Placement: Mech System Collection Space

Mechanical System Logger Locations:

Outside Air/Preheated Air Cooled Air Downstream Reheat

Heated Air Supply Air Return Air Other__________

Mixed Air

Is System Capable of Daily Setbacks

YES NO

2 Week Test

Date	Normal Temp/RH	Setback Temp/Rh	Duration	Recovery Time	Other Changes Made to the System	Notes

Daily Walk-through Log: Check if System and Space are Following Setback Schedule

Mon	Tues	Wed	Thurs	Fri	Sat/Sun

Daily Log: Verify That the Space and System Return to Normal Operation

Mon	Tues	Wed	Thurs	Fri	Sat/Sun

Daily Check of the BMS System:

Mon	Tues	Wed	Thurs	Fri	Sat/Sun

Weekly Data Pull

Post Tests:

Did Setbacks Occur as Planned: Yes No

Did Space Temperature Return to Normal: Yes No

NOTES:

ENERGY-SAVING STRATEGIES:
ADJUSTING FAN SPEED

Goal: To use a variable speed drive (VSD) or variable frequency drive (VFD) to reduce the speed of fans on an air handling unit to achieve energy savings when occupancy is low with minimal impact on the preservation environment.

Advantages	Disadvantages
Often simple mechanical control	Potential to forget to restore equipment to normal operation
Can result in significant energy savings	A VSD or VFD is needed to adjust fan speed

Description of Potential

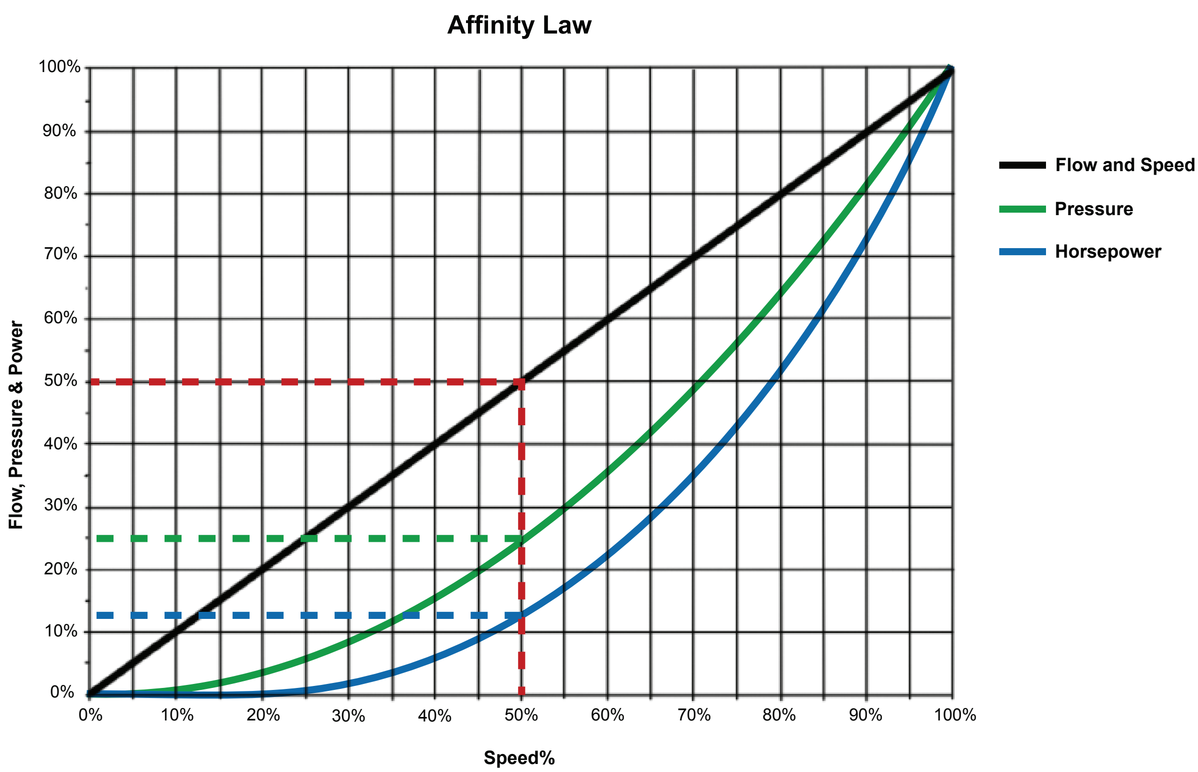
The fan motors on air handling units (AHU) account for most of the electrical consumption of a unit. Depending on an original design and the energy loads in the AHU zone, it may be possible to operate the fans on an air handling unit at reduced speeds. Zones that see little energy load returned back to the unit, but where the fans are running at 100% capacity, are good candidates for this strategy. Reduced fan speeds use significantly less power than maximum operation and can often be employed, typically during unoccupied or low occupancy times, but occasionally during regular operating hours as well. During this reduction of power the coils in the HVAC system operate as normal, but reducing the air flow results in less energy work, allowing for significant energy savings over time at both the fan and individual coils and components.

A reduction in fan speed is not meant as a means to manipulate the temperature or relative humidity within a space. The goal is to reduce the fan speed operation without changing the downstream air conditions, and should have little to no effect on the quality of the preservation environment for the collection.

Fan speed reduction will have an effect on the number of air changes within a facility. Required air changes per hour are typically dictated by building and construction codes based on maximum potential occupancy of the space. However, most buildings/zones are rarely at their maximum occupancy, creating a situation where reduced operation may be feasible even during occupied hours. As long as the set points are being met, and the appropriate amount of outside air is introduced for occupancy needs, reductions in fan speed can often be conducted with minimal impact on occupants in the zone.

To adjust fan speeds an AHU must have a VFD installed on the motor. These drives vary the frequency and voltage supplied to a fan motor in order to alter the speed, impacting the rate of air flow moved by the fan. The physical result is similar to using a dimmer switch on a residential fan or light fixture. The VFD is often controlled by a BMS. It is common for fan speed to be altered based on downstream pressure within the system – as pressure increases, usually as a result of closed VAV boxes, the fan speed reduces.

The relationship of fan speed, power and flow is expressed through fan affinity laws. Using the affinity laws, one can see how the fan power consumption does directly relate to the fan speed and the flow of the air. Any given reduction in fan speed results in a cubic reduction in fan horsepower. Slowing the fan speed down to 50% may mean a 50% reduction in the flow of air but will also yield an 87% reduction in horsepower. Strategies like this can be effective to save energy when space loads are minimal and less air flow is needed, during occupied or unoccupied hours. By installing and using a VFD you can control the fan to adapt the air flow to the needs of the environment (see the fan power graph below which shows fan power in relation to air flow).



Understanding this relationship can help a facility manager determine how air flow will be affected based on the reduction of fan speed. This will also help estimate how much energy will be saved at the fan motor.

Requirements:

- A VFD for reducing the fan speed
- Ability to program system operation
- Automated control of mechanical system and VFD are preferable
- Knowledge of hours of operation and/or work schedule for the facility
- Data logging within the VSD/VFD to record fan amps (if you want to quantify energy savings)
- Data logging within the mechanical system (if quantified energy savings at individual components are desired)
- Data logging in the collection space (to monitor the storage environment for any potential changes)

Critical Data Points:

- Preservation
    - Space data from each space affected by the system during the adjustments
    - Identification and monitoring of potential microclimate areas that may fluctuate differently than the rest of the space
- Energy
    - Data from each location in the system where a component can mechanically work on the air:
        - Return air
        - Mixed air
        - Pre-heated air
        - Cooled air
        - Heated/supply air
        - Fan amps
        - Downstream reheats
        - Others (as needed)

Pre-Testing:

- Verify the hours of operation and staff work schedule for the facility
- Notify all staff of fan speed and airflow adjustments – occupants may feel less air movement if experiments are conducted during occupied hours

System Notes:

- Verify the type of system that serves your space
- Verify that there is a VSD/VFD on the fan

Selection Criteria/Variables That Impact Potential:

- Building Envelope:
    - Due to reduced air volume during the fan speed adjustment the air pressurization in the facility may change. This may cause a positively pressurized space to become neutral or a neutral space to become negatively pressurized.
        - Infiltration of outside air may produce microclimates causing the temperature in some areas to drop lower than desired. This could impact the relative humidity level
        - Areas of concern: near doors, windows, open plenum returns, stairwells, etc.

- Occupancy:
    - Staff who work after hours may notice reduced air flow in the space
        - Complaints to facility managers may result in unforeseen adjustments
        - Test results may be skewed if facility mangers or staff members alter fan speeds due to complaints
- Space Load:
    - Ensure that staff are not using independent space heaters that can be left on and may add extra heat to the space
- Power:
    - Verify that in the event of a power outage the system operation is restored and the system is working properly
- Mechanical System:
    - Some fans are not capable of operating at low speeds
        - Consult your facilities or maintenance personnel for possible limitations to the fan operation
    - A reduction of the fan speed may lead to a slight gain or reduction in temperature as the air crosses the coils

Shutdown Experimentation (Test) and Implementation:

PREPARATION:

- Complete documentation, data gathering, and analysis steps for the system/spaces in question
- Use the Selection Criteria above to review whether the system is a good candidate for fan speed adjustments
- Confirm that appropriate data gathering capabilities are deployed and determine who will pull and check data, and how often
    - The frequency of data pulls and analysis is up to the institution and is based on staff scheduling and the level of risk management desired for a particular collection space. Common approaches include:
        - A daily walk-through of the space to be sure that normal daytime set points are being held
        - Weekly data pulls from loggers to analyze data
- Determine test parameters:

- Occupied space fan speed setbacks
    - Use caution when testing fan speed setbacks during occupied hours
    - Occupied spaces have specific amounts of air changes required due to use. Fan speeds should be selected that consider human comfort as well as meeting code requirements.
    - If testing in occupied spaces is desired be sure to meet the desired amount of air changes required by code for the space
- Continue to use the typical temperature and relative humidity set points; do not try to experiment with fan speed alterations and set point changes simultaneously
- Length of fan speed adjustment test
    - Typically, an initial test should be allowed to run for two weeks. Environments can respond differently based on outdoor weather conditions—two weeks is a reasonable compromise between gathering a representative sample set for a season and limiting any long-term risk
    - Set a start and end date for the test period
    - The fan speeds that will selected can be introduced at any time of the year depending on loads from the AHU zone.

- Communicate the fan speed adjustments to collections and facilities staff responsible for managing the areas involved:
    - Discuss the potential impact on human comfort in the space
        - Be sure staff do not use alternative methods of heating during the testing period. This will impact the energy load in the space, potentially influencing the experiment. If the experiment is successful, normal space set points should be maintained.
        - Propose a start and end date for the test period and make sure that this fits with departmental needs
        - Set up a communication structure during the test period for any environmental complaints or work-orders associated with comfort or temperature complaints

ON THE TEST START DATE:

- Facilities staff should physically confirm that the fan speed adjustments are in place
- Facilities staff should notify team members on the day that the testing starts
- Collections staff should notify other staff members on the day that the testing starts

DURING THE TEST PERIOD:

- It should be verified that the fan speed adjustment was initiated
- Facilities staff should be sure to forward any complaint calls to the facilities team representative
- Daily walk-through of test space and check of space dataloggers for any deviation from the desired temperature and relative humidity (Collections staff)
- Follow schedule for data retrieval from space and mechanical systems
- Regular check of BMS for alterations in system operation (Facilities staff)
- First data retrieval as per test schedule
    - Look for evidence of fan speed reduction in data from the fan amp logger
        - Adjustments should appear as a reduction in fan amps
        - BMS interface may be able to trend fan speeds as a secondary check to confirm operation
        - If the adjustments do not appear to be employed, work with facilities staff and/or controls technicians to find and resolve the problem
    - Initial evaluation of results of test adjustments
- If the results of the initial evaluation are acceptable, continue using fan speed adjustments until the end of the testing period

AT THE END OF THE TEST PERIOD:

- Conduct a final walk-through of systems and spaces
- Retrieve and upload data from space and mechanical system dataloggers
- Conduct final analysis of the test data as a team
- Meet with collections and facilities staff that manage the area to discuss any observations on their part during the test period and communicate the results of the final data analysis to them
- Results of analysis will determine the next step:
    - If test results were favorable
        - Continue using the adjusted fan speeds
        - Consider using a slower speed
    - If test results were not favorable
        - Consider altering the test in some manner (raising the fan speed) to achieve more acceptable results

- If testing of all strategies for that AHU are complete, remove mechanical system dataloggers and reset them to be used in experimentation for other systems
- Compile, quantify, and report test results to appropriate Administrative staff

IMPLEMENTATION/MAINTENANCE:

Once the team has determined the appropriateness of the fan speed adjustments the process enters the implementation/ maintenance phase. At this point, the team should be satisfied that they have decided upon an optimal fan speed and hours combination to save the most energy without impacting the preservation conditions in the zone.

- Document all adjustments made to fan speeds
    - Add the fan speed adjustments to the schedule for the AHU, both in programming and in any written documentation

Evaluating Test Results

SPACE DATA

- There should be no change in downstream conditions.

MECHANICAL SYSTEM DATA

- Use the datalogger on the fan (installed by a qualified electrician or maintenance technician) to see if the fan is modulating correctly.

REMINDERS FOR MAXIMIZING EFFECTIVENESS

Be sure to fully inform staff:

- In occupied spaces inform staff of fan speed and airflow adjustments in advance – the air may feel “still” compared to normal air movement.
- Remind staff to communicate issues to the environmental management team, and to avoid adjusting space set points during the experimentation phase.

Fan Speed Log Sheet for Zone/AHU#

[Organization Name]

Collection Staff:

Facilities Staff: Fan Amp Logger: Yes No

Mechanical System Logger Locations:

Outside Air/Preheated Air Cooled Air Downstream Reheat

Heated Air Supply Air Mixed Air Return Air Other__________

2 Week Test

Date	Fan Speed 'Normal'	Normal Operating Hours	Fan Speed Adjusted	Adjusted Operating Hours	System Return to Normal	Notes
					Yes / No	
					Yes / No	
					Yes / No	
					Yes / No	
					Yes / No	
					Yes / No	
					Yes / No	
					Yes / No	
					Yes / No	
					Yes / No	
					Yes / No	
					Yes / No	
					Yes / No	
					Yes / No	

Daily Walkthrough Log: Check if System and Space are affected

Mon	Tues	Wed	Thurs	Fri	Sat/Sun

Daily Log: Verify that the System Returns to Normal Operation

Mon	Tues	Wed	Thurs	Fri	Sat/Sun

Daily Check of the BMS System:

Mon	Tues	Wed	Thurs	Fri	Sat/Sun

Weekly Data Pull

Post Tests:

Did the fan speed reduce as expected: Yes No

Did System return to normal operation: Yes No

Are the fan speeds worth continuing: Yes No

NOTES:

ENERGY-SAVING STRATEGIES:
SEASONAL SET POINTS

Goal: To use appropriate seasonal temperature and relative humidity settings to improve the preservation environment and reduce energy impacts.

Advantages	Disadvantages
Often simple mechanical control	Potential to forget to reset equipment to next seasonal operation
Potential to seasonally improve environmental conditions for collection	Seasonal decreases in temperature may increase human comfort complaints
Cumulative energy savings over the seasons	Potential for significant fluctuation in poorly insulated buildings

Description of Potential

Many institutions utilize set point changes as a way to create the most efficient and beneficial preservation environment on a seasonal basis. AHU zones that have traditionally maintained constant set point conditions throughout the year may be missing opportunities to both reduce energy consumption and improve preservation conditions. Research has helped define safe ranges of RH for many collection materials; that data, combined with the knowledge that cooler temperatures slow the rate of chemical decay for organic materials can allow institutions in seasonal climates to take better advantage of natural outdoor weather conditions.

Seasonal set point controls typically work in two ways. Space RH set points in hot and humid seasons may be adjusted slightly higher – to 55-60% RH maximum depending on the collection needs and risks – to reduce energy consumption on dehumidification with minimal impact on the overall preservation risk. In climates with seasonally cool and dry outdoor conditions, interior temperature set points are lowered, reducing energy consumption for heating and humidifying (lower temperatures typically help keep the RH higher), and sometimes significantly improving preservation quality. These lower set points are usually instituted in the middle or end of the fall season and then raised to summer set points in early to mid spring (in the case of a mid-Atlantic environment).

The intention of the set point change is primarily to improve the preservation environment; energy savings are an additional benefit and may not be as immediately pronounced as with other strategies. When utilizing set point changes during both hot and cool seasons, summer set points may result in slightly higher rates of chemical decay, but these are typically offset by using corresponding winter set point changes to improve chemical decay rates. The end result is often a similar to slightly increased overall preservation quality maintained at lower energy costs due to more appropriate energy allocation. Institutions may also choose to apply any winter energy savings achieved to their summer operation, and work to improve summer dehumidification and preservation quality.

Lowering interior temperatures during cooler months does not mean increasing the amount of outside air. The use of more outside air could result in a lower temperature than normal at the heating coil, causing the coil to use more energy to reach the set point condition. Another potential side effect of too much outside air in the winter is a lower than normal dew point temperature, which may cause humidifiers on the system to operate more frequently. If there is no humidification, the low dew point could result in dangerously low relative humidity levels for the collection.

For winter set point adjustment, the intention is to use less heating on the supply air to produce a cooler temperature. In this scenario the return air is brought back into the system slightly cooler than the supply air due to presumed heat loss from the space. This air combines with minimal outside air and the condition of this mixed air is likely slightly cooler than the return air. When this mixed air reaches the heating coil, the air is heated to the new supply air temperature seasonal set point. The lower the desired space temperature the less work the heating coil needs to perform to achieve it. Note that this strategy may not work for zones that are completely interior to a building, with no exterior exposure or heat loss.

Using set point changes in occupied spaces can be tricky. People become accustomed to warm space temperatures and tend to notice temperature drops of even a few degrees. Some occupants are satisfied in warm spaces around 70°F and others can be comfortable in temperatures as low as 65°F. If the team is proposing experimentation in occupied spaces, work closely with staff in the zone to determine appropriate tests and compromises between human comfort, preservation goals, and energy benefits.

Requirements

- Automated control of mechanical system is preferable
- Ability to program system operation
- Knowledge of temperature and RH limits of vulnerable collection materials
- Data logging within the mechanical system (if you want to quantify energy savings)
- Data logging in the collection space (to monitor the storage environment for improvement in conditions or any potential risk)

Critical Data Points

- Preservation
    - Space data from each space affected by the system during seasonal changes
    - Identification and monitoring of potential microclimate areas that may fluctuate differently than the rest of the space (especially near doors, windows, or anywhere that outside air may infiltrate)
- Energy
    - Data from each location in the system where a component can mechanically work on the air:
        - Return air
        - Mixed air
        - Pre-heated air
        - Cooled air

        - Heated/supply air
        - Fan amps
        - Downstream reheats
        - Others (as needed)

Pre-Testing

- Use Dew Point Calculator to evaluate the temperature and relative humidity conditions you intend to use
    - Analyze dew point graphs for the selected space over time in eClimateNotebook to determine the expected dew point. Use this dew point with the selected temperature to find the potential relative humidity for the space.
- Verify the date when the system typically switches from cooling to heating mode with your facilities representative
- Consider space occupancy and determine whether two different set points need to be used (one temperature for operating hours and a lower temperature for after work hours)

System Notes

1. Be sure to set start and end dates for the seasonal changes. Data in eClimateNotebook (www.eClimateNotebook.com) can be used to identify the seasonal swing points.
2. Verify the type of system that serves your space. If the AHU operates as a subcool/reheat arrangement, be careful of the misconception that turning the temperature up in the summertime in a space means you are using less energy. With sub-cool and reheat systems, turning the heat up in the summer will use more energy.

Selection Criteria/Variables That Impact Potential

- Outdoor Climate
    - Take advantage of cooler outside temperatures by employing passive methods to let the space temperature drop naturally
    - Consider relaxing RH set points to safe upper limits (55-60% RH for many collections) during dehumidification operation to allow for reduced dehumidification, or cooler temperature set points to reduce the rate of chemical decay
- Building Envelope
    - Infiltration of outside air near doors, windows, open plenum returns, stairwells, etc. may produce microclimates causing the temperature in some areas to drop lower than desired and could impact relative humidity levels.

- Occupancy
    - Comfort complaints may result from any set point change
        - Complaints to facility managers may result in set point adjustments
        - Test results may be skewed if facility mangers or staff members alter space temperatures due to comfort complaints
- Space Load
    - Ensure that staff are not using independent space heaters that may provide false readings or add extra heat to the space
- Power
    - Verify that in the event of a power outage the set points will return to the desired seasonal settings and not revert to the original space set points

PREPARATION

- Complete documentation, data gathering, and analysis steps for the system/spaces in question
- Use the selection criteria above to review whether the system/space is a good candidate for seasonal set points
- Confirm that appropriate data gathering capabilities are deployed, determine who will pull and check data, and how often. The frequency of data pulls and analysis is up to the institution and is based on staff scheduling and the level of risk management desired for a particular collection space. Common approaches include:
    - A daily walk-through of the space to be sure that set points are being held
    - Weekly data pulls from loggers to analyze data
- Determine test parameters
    - Occupied space seasonal set point changes
        - Occupied spaces are limited in the amount they can be cooled due to use. Set points should be selected that consider human comfort as well as collection risks.
        - Spaces that are accessed often but not staffed can use cooler temperatures, however the comfort of the individuals that may access the space should be considered. Coats or sweaters may be provided for those who need to work in the collection.
    - Unoccupied space seasonal set point changes
        - Unoccupied spaces benefit from the ability to lower the temperature significantly compared to occupied spaces. When evaluating unoccupied spaces the most significant factors may be the relative humidity level or the frequency of use.
    - Be sure that the temperature you are using produces a safe relative humidity

- Length of seasonal set point test
    - Set a start and end date for the test period.
        - Seasonal set points are usually introduced in mid to late fall and the summer set points are reinstated in early to mid spring.
    - Typically an initial test should be allowed to run for two weeks. Environments can respond differently based on outdoor weather conditions and two weeks is a reasonable compromise between gathering a representative sample set for a season and limiting any long-term risk.
- Communicate the set point changes to collections and facilities staff responsible for managing the areas involved.
    - Discuss the potential impact on human comfort in the space
        - If the set point changes will occur in occupied spaces be sure all staff are aware of the changes and that they can plan accordingly
        - Be sure staff do not use alternative methods of heating during the testing period
        - Set up a communication structure during the test period for any environmental complaints or work-orders associated with comfort or temperature complaints
    - Finalize a start and end date for the test period and make sure they with departmental needs

ON TEST START DATE

- Facilities staff should physically confirm that the system has switched over to the seasonal set points
- Facilities staff should notify team members that the testing has begun
- Collections staff should notify other staff members that testing has begun

DURING THE TEST PERIOD

- Facilities staff should be sure to forward any comfort complaint calls to the facilities team representative
- Collections staff should conduct daily walk-throughs of test space and check space dataloggers for deviation from the desired temperature and relative humidity
- Follow schedule for data retrieval from space and mechanical systems
- Facilities staff should conduct regular checks of BMS for alterations in system operation
- First data retrieval as per test schedule
    - Look for evidence of set point change in data from both the space and mechanical system dataloggers
        - If seasonal set points do not appear to be employed, work with facilities staff and/or controls technicians to find and resolve the problem

    - Evaluate results of test set points

- If the results of the initial test are acceptable, continue the seasonal set points protocol until the end date

AT THE END OF THE TEST PERIOD

- Conduct a final walk-through of systems and spaces
- Retrieve and upload data from space and mechanical system dataloggers
- Conduct final analysis of the test data as a team
- Meet with collections and facilities staff that manage the area to discuss any observations on their part during the test period and communicate the results of the final data analysis to them
- Results of analysis will determine the next step:
    - If test results were favorable
        - Continue using the conditions through the season
    - If test results were not favorable
        - Consider altering the test in some manner (raising/lowering the desired temperature) to achieve more acceptable results
- If testing of all strategies for that AHU is complete, remove mechanical system dataloggers and reset them to be used in experimentation for other systems
- Compile, quantify, and report test results to appropriate administrative staff

Once a team has determined a seasonal set point procedure, settled on a schedule to follow, and the set points to use, the process enters the implementation/maintenance phase. At this point, the team should be satisfied that they have tested the potential variants of temperature and relative humidity set points allowable, and have chosen the best operation for the needs of both preservation and energy savings.

Implementation/Maintenance

- If the team has determined that using seasonal set points is desirable be sure to have solid start and end dates for the use of seasonal set points that are agreed upon before implementation
- If possible, add set points to the schedule for the AHU, both in programming and in any written documentation
- Be sure to add the set point changes to the facility calendar and the collections calendar as a reminder to verify the implementation of winter set points and return to summer set points

Evaluating Test Results

SPACE DATA

- Look for variations that correspond to the seasons.
    - Temperatures in spaces should be lower during the time of year when it is cooler outside than when it is warmer outside. Having a few anomalous days should not be an issue, but the set points should correspond closely with outside conditions to maximize effectiveness.
    - Temperature set points should be appropriate so that do not result in relative humidity issues (i.e. the temperature in the summer may have to be higher than in the winter to keep the relative humidity artificially low).

MECHANICAL SYSTEM DATA

- Use the supply air dataloggers to see that the spaces are receiving the desired conditions.
- In a sub-cool/reheat system, the heated air and humidified air dataloggers should be doing less work than previously during the winter.

REMINDERS FOR MAXIMIZING EFFECTIVENESS

Be sure to fully inform staff:

- Not to adjust the temperature due to comfort issues in occupied spaces
- To dress for lower temperatures in unoccupied spaces

ENERGY-SAVING STRATEGIES:
OUTSIDE AIR REDUCTIONS

Goal: To use only the amount of outside air necessary to prevent the build-up of gases that can pose risks for collections and human health, and keep spaces properly pressurized to reduce the load at the AHU for energy savings and potential increase in preservation quality.

Advantages	Disadvantages
Significant potential energy savings	Potential for indoor air quality issues
Often simple mechanical control	Potential air balancing/pressurization issues
Potential for improvement in preservation quality	

Description of Potential

Outside air is often the single largest source of energy load that AHUs, especially those serving primarily collections zones, have to contend with. In hot, humid climates or seasons, the majority of a dehumidification load is brought in on outside air, and in cool, dry climates or seasons, outside air increases the need for heating and humidification. Due to the specific environmental needs for collections preservation – cool temperatures at moderate RHs, which translate to a range of dew point conditions rarely provided outdoors in many climates – mechanical systems are nearly always working to overcome outside air conditions in order to provide the appropriate preservation conditions. Filtration load also becomes an issue in most buildings, as a large portion of the particulate and/or gaseous filtration load comes directly from the outdoors.

Outside air is typically introduced to buildings through AHUs for two primary purposes – as a means of providing fresh air for indoor air quality, and as a source of make-up air to provide for volume lost. Design outside air quantities for mechanical systems are typically based on a standardized formula in which the modeled maximum potential occupancy in the zone plays a large role. Local and state codes also play a significant role as many assign certain minimum percentages of outside air intake that must be met.

Typically, the minimum outside air quantities used in AHU control are based on the design criteria. Once initially programmed, the quantities often remain unchanged. The energy industry's recent increased use of CO_2 sensors in AHU control has shown that many systems can see significantly reduced outside air quantities even in normally occupied zones due to patterns of non-peak occupancy. Essentially, the sensors read the CO_2 ppm in the zone (either in the space or at the return air) and will modulate the outside air intake based on set point conditions. As a key indicator of human occupancy, low CO_2 levels in a space often mean that little or no outside air is required; high CO_2 levels will command the outside air damper to open and allow more fresh air in.

CO_2 monitoring and control capability means that even occupied spaces may be able to use reduced volumes of outside air during occupied hours. For systems that do not currently have CO_2 sensors as a control feature, reduced outside air tests can still be performed during unoccupied hours for public and work areas, and may be tested during daytime hours for zones that are primarily or entirely dedicated to collections storage. Experimentation and control are made significantly easier if the outside air damper is able to modulate automatically. Tests can still be performed with manual dampers, but the process requires more of a "trial and error" approach.

Economizer controls are a common energy reduction feature that allow increased volumes of outside air into the building as "free cooling" and are often seen on systems that serve human-occupied spaces. Unfortunately, these are not typically beneficial to collections preservation environments. Most economizers are based solely on a sensible temperature control, which may allow increased air volume at an inappropriate moisture content to enter the building.

Some economizers are controlled based on enthalpy, or the total energy content of the air (both sensible and latent). While this method takes moisture and its energy into account, it does not look specifically at dew point, or whether the air volume is at the actual appropriate condition for preservation. The result is that, even with the correct enthalpy condition, the unit may still have to perform moisture control work in order to achieve the correct dew point for the space. Generally speaking, economizer controls do not often work well for collections storage spaces – the amount of time that outdoor weather conditions provide the correct combination of moisture content (dew point) and cool temperatures is simply too small. From an energy and preservation perspective, reducing the total outside air volume to the absolute minimum necessary is far more beneficial.

Most collections storage zones receive far more outside air than they actually require – the result is increased energy expenditure working on loads that were not generated inside the zone, but that were brought in directly from outdoors. Expending energy and the unit's total capacity on outside air can also result in less-than-optimal preservation conditions; if that energy were focused on removing additional energy load from the AHU zone, many systems may have the potential to maintain better preservation environments, especially during extreme weather conditions.

If the AHU zone in question is primarily or entirely dedicated to collections storage, there is little need for outside air beyond two possible factors:

1. Original system design and balancing requirements
    - Be wary of potential balancing issues if testing outside air reduction strategies. Airflow design for many systems is based on a minimum quantity of outside air – if the return air is not capable of bringing back the necessary volume of air, the zone could experience pressurization or airflow issues.
    - State and local codes for minimum air may still apply and will take precedence.
2. Turnover of air to exhaust any off-gassing from collection materials (which CO_2 monitors will not address)
    - A wide range of materials off-gas, including nitrate and acetate film, rubber and plastic objects, and certain minerals and biological materials found in natural history collections. Even the cellulose of paper and books emits gaseous products as it degrades. Past treatments – for example, pesticides applied to specimens – can introduce pollutants to the air. Additionally, both indoor and outdoor air pollutants can accumulate in indoor air spaces. Mechanical systems will not take these pollutants

into account in their operation, so analysis of the off-gassing levels in collection spaces and establishment of acceptable levels might be performed independently.

In summary, to address the concerns of outside air reduction, environmental management teams may want to work with an institutional Environmental Health and Safety Officer during the experimental design and test period to ensure that human needs are met and in compliance with state and local regulations. Careful testing should be performed so that collection spaces do not go negative in pressure as a result of not enough air, encouraging the infiltration of unconditioned air from surrounding spaces and outside, as well as particulates. Also consider the potential build-up of off-gassing, the products of which can often accelerate degradation of collections materials without special monitoring to ensure they remain within safe limits.

Candidate systems for outside air reduction testing may include:

- Systems with a large percentage of outside air for a zone with little or no air loss due to exhaust fans or fume hoods
- Systems where data analysis shows that the majority of the energy work performed is due to the outside air intake quantities
- Collections storage zones with minimal daytime occupancy and low rates of off-gassing
- Occupied zones in which normal occupancy is significantly less than their maximum occupancy
- Occupied zones that have patterns of little or no occupancy, such as nights or weekends

Potential energy savings from outside air reduction will vary based on the initial quantity of outside air used, the total reduction of outside air quantities, and the schedule during which the reduction occurs.

Requirements

- Automated control of the outside air damper is preferable
- Ability to schedule system operation and damper positions
- Identified zone served by the air handling unit to be tested
- CO_2 monitoring or control is preferable
- Data logging within the mechanical system (if quantified energy savings are desired)
- Data logging in the collection space (to monitor the preservation environment for any potential risk)

Critical Data Points

- Preservation
    - Space data from each space affected by the system that is tested
    - Identification and monitoring of potential microclimate areas that may fluctuate differently than the rest of the space
- Energy

- Data from each location in the system where a component can mechanically work on the air:
  - Return air
  - Mixed air
  - Pre-heated air
  - Cooled air
  - Heated/supply air
  - Fan amps
  - Downstream reheats
  - Others (as needed)

Pre-Testing

- Be certain that outside air dampers modulate properly based on control commands – occasionally damper modulation is programmed backwards, where the actuator opens the dampers even though the control is to close them.
- CO_2 monitoring or sampling is helpful to get a baseline of fresh air requirements in AHU zones, from a human occupancy perspective.

System Notes – Code Requirements

- Municipalities or states may have strict requirements for minimum outside air percentages for a space. If these quantities are excessive for the specific zone in question, CO_2 monitoring and control can sometimes satisfy the code, or the team may have to work with local code enforcement to discuss permission for testing.

System Notes – 100% Outside Air Systems

- Some AHU designs are based on 100% outside air intake – no return air is provided to the unit at all. In these cases, outside air reduction strategies need to be based on necessary total air volume requirements for the zone.

Selection Criteria/Variables That Impact Potential

- Outdoor Climate
  - Climates with extreme conditions – those that are significantly different from the indoor set point conditions – can have the greatest energy savings for outside air reduction.
- Building Envelope

    - The less exterior wall exposure in the collections space, the more likely that outside air is the majority of the energy load, especially for collections storage zones.
- Occupancy
    - Zones with consistent, high occupancy rates may not be appropriate for experimentation.
    - Zones with sporadic high occupancy rates – galleries, event areas – may benefit from CO_2 control to only allow outside air into the building when necessary.
    - Collections storage zones, or zones with little occupancy on a regular basis or daily pattern may be excellent candidates for experimentation.
- Collections off-gassing
    - Some collections materials off-gas. If this is an issue in a collections zone, outside air may need to remain at a higher percentage to remove pollutants for either human health or collections preservation concerns.

Outside Air Reduction Experimentation (Test) and Implementation

PREPARATION

- Complete documentation, data gathering, and analysis steps for the system/spaces being evaluated.
- Use the selection criteria above to review whether the system/space is a good candidate for outside air testing.
- Confirm that the system is capable of controlling outside air intake quantities. If control is manual, experimentation will require greater involvement and attention from the facilities staff.
- Confirm that appropriate data gathering capabilities are deployed and determine who will pull and check data, and how often. The frequency of data pulls and analysis is up to the institution and is based on staff scheduling and the level of risk management desired for a particular collection space. Common approaches include:
    - A daily walk-through of the space to be sure that normal daytime set points are being held
    - Weekly data pulls from loggers to inspect nighttime fluctuation
- Determine test parameters
    - Outside air reduction during unoccupied hours
        - Outside air intake quantities should be returned to normal operation at least one hour before the zone/building is occupied.
    - Outside air reduction in occupied zones
        - Tests should be conducted incrementally based on estimated regular occupancy versus designed maximum occupancy. Systems running at 20% outside air may be tested with 10-15% outside air (depending on code requirements) to see how the zone responds.

- CO_2 monitoring/control
    - For systems that have CO_2 monitoring, review the CO_2 ppm set point (the threshold where the sensor tells the system to allow more outside air in) and determine if it is appropriate based on trended CO_2 conditions.
    - Review control to see whether no call for outside air means that the outside air intake is closed, or simply set to a minimum percentage.
- Length of test
    - Typically an initial test should be allowed to run for two weeks. Interior environments can respond differently based on outdoor weather conditions and interior energy loads.

- Communicate the outside air reduction plan to collections and facilities staff responsible for managing the areas involved
    - Discuss the potential impact on human comfort in the space
        - Set up a communication structure during the test period for any environmental complaints concerns
    - Finalize a start and end date for the test period and make sure that this fits with departmental needs

ON TEST START DATE

- Facilities staff should physically confirm that the outside air damper modulates or is closed appropriately during the first test period
- Facilities staff should notify team members and building facilities staff that the testing has begun
- Collections staff should notify other staff members that testing has begun
- Facilities staff should physically confirm that the outside air dampers open automatically, or are manually opened, at the scheduled time

DURING THE TEST PERIOD

- Collections staff should conduct daily walk-throughs of tested space and check space dataloggers for deviation from set point range
- Follow schedule for data retrieval from space and mechanical systems
- Facilities staff should conduct regular checks of BMS for alterations in system operation
- First data retrieval as per test schedule
    - Look for any evidence of environmental issues in both the space and mechanical system dataloggers
        - Reduction in energy load from outside air may result in different patterns within the

    - mechanical data, including lower dew points during dehumidification seasons or higher dew points during humidification seasons.
    - Review data to ensure that the system and space are adjusting to to the different energy loads appropriately.
  - Initial evaluation of outside air reduction tests
- If the results of the initial test are acceptable, continue the outside air reduction test protocol until the end date

AT THE END OF THE TEST PERIOD

- Conduct a final walk-through of systems and spaces
- Retrieve and upload data from space and mechanical system dataloggers
- Conduct final analysis of the test data as a team
- Meet with collections and facilities staff that manage the area to discuss any observations on their part during the test period and communicate the results of the final data analysis to them
- If no issues due to outside air reduction have been recorded or reported, allow the procedure to continue through to the implementation phase
- Results of analysis will determine the next step:
  - If test results showed challenges with maintaining space set points due to airflow issues, or if there were any human health or comfort issues, consider altering the test in some manner (smaller reduction quantities, shorter test periods during unoccupied hours) to achieve more acceptable results, or discontinue the strategy.
- If testing of all strategies for that AHU is complete, remove mechanical system dataloggers and reset them to be used in experimentation for other systems
- Compile, quantify, and report test results to appropriate administrative staff

Once a team has determined an outside air reduction procedure should be adopted, and settled on a schedule based on zone occupancy, the process enters the implementation/maintenance phase. At this point, the team should be satisfied that they have tested the potential variants of operations and schedules, and have chosen the best operation for the needs of both preservation and energy savings.

Implementation/Maintenance

- Add the outside air intake quantities and schedules, and the CO_2 control parameters, if any, to the normal sequence of operations for the AHU, both in programming and in any written documentation
- Repeat the test procedure seasonally or as necessary
- Collections staff should continue pulling and reviewing space data once a month. Any variation from

documented expected space conditions should be watched and reviewed with the team

- Review and analyze space data (via dataloggers) and mechanical system operation (via BMS) every 4 to 6 months to ensure that the outside air reduction strategy is in place, and is using appropriate quantities at the specified times
- If the operation deviates from the intended sequence of control, use the system and space documentation and compare those to the current operation and environmental behavior to try and diagnose the problem
    - Revert to original design outside air quantities until the problem is resolved
- Repeat testing procedure as necessary to determine the appropriate operation

Evaluating Test Results:

MECHANICAL SYSTEM DATA

- Mixed air conditions should more closely match return air conditions after outside air use has been reduced.
- Cooling coils or desiccant units should see reduced work during dehumidification seasons
- Heating coils and humidifiers should see less work during cool or dry seasons

COLLECTIONS SPACE DATA

- Spaces still operate at positive or neutral pressure. This can be tested by holding a lightweight object such as tissue paper up to a door; open the door slightly, and ensure the paper does not blow towards the collection space.
- Monitoring levels of off-gassing can be difficult. Coupons and A-D Strips may be useful to gauge approximate levels. Spot measurements can also be performed for likely pollutants using instruments for air sampling.

ENERGY-SAVING STRATEGIES:
LIGHT REDUCTION

Goal: To improve preservation and achieve energy savings by altering the duration of time that lights are used, the type of lighting used, and altering light use habits.

Advantages	Disadvantages
Some adjustments can be simple (adjust timers, change bulbs)	Some adjustments require an investment (install new fixtures, install motion switches)
Cumulative energy savings for electrical and system energy over time	Energy savings can be minor compared to adjustments in HVAC operation
Reduces the collections' exposure to damaging light	

Description of Potential

According to the Center for Climate and Energy Solutions, lighting in commercial buildings is on average nearly 18% of the total energy consumption. Though lighting is important to any facility, many times energy is wasted by leaving lights on in unoccupied rooms or even for hours after a facility has closed. One of the simplest ways to help manage energy within a facility can be through light reduction. Reduction of light usage will not generate immediate major savings; however, if done properly and adhered to, the savings will be cumulative throughout the year and over time. Depending on the bulbs in place, it can also have an impact on cooling costs, since any added heat load must be removed by the mechanical system.

Light exposure, a combination of duration and intensity, can have serious effects on collection materials and is irreversible. Damage can include:

- From exposure to infrared light: brittleness, distortion
    - Heat emitted as a result of operation can cause materials to dry out, resulting in damage such as warping, shrinking, or cracking. This is particularly a concern for materials close to light fixtures that are on regularly, such as in exhibit display cases.
- From exposure to visible light: fading
    - Certain colorants and materials are susceptible to fading, which can make it difficult to interpret the original material correctly either because it is too faint or because perceived color shifts can occur (the loss of yellow in originally green images leaves blue as the perceived color).

- From exposure to ultraviolet (UV) light: yellowing, weakening and disintegration
    - Wavelengths in the ultraviolet are shorter and of higher energy than infrared or visible, so the damage can be structural.

Certain types of materials, such as photographs, watercolors, color on paper, and some textiles, are more vulnerable to the effects of light than others. Materials also vary in how they respond to the spectrum of different light sources, though generally the purple-blue wavelengths are among the most damaging with other sensitivities according to the specific materials. Microfading tests and damage spectra can be useful in determining how an individual work will respond to light, but general guidelines for light exposure based on material type are also available.

Overview of Strategy

Reduction of lighting is not simply turning off the lights when the space is unoccupied. It involves taking a step back and considering all potential options and their effects. For example, switching from T12 florescent bulbs to LED will most likely eliminate the added heat from the bulbs in the space. This may not be noticeable with only one or two fixtures but may be very noticeable if there are multiple fixtures in one room or hundreds in the AHU zone.

It is also important to consider alternative ideas for light reduction. While manual switching off lights is a great idea, these lights can, at times, be forgotten about and the lights can be left on. In this case, consider whether there is potential to install motion sensors to ensure that lights do turn off. There is also a difference in actual and required lighting. The required lighting to work in a space may be much less than the actual lighting. Often spaces have too much lighting and some of the light can be reduced or removed without having an impact on the performance of the space.

Reducing the amount of light used can be done on the micro- or macro-level. The process may be looking to reduce lighting in a few rooms, the AHU zone, or may incorporate the entire facility. It begins by asking a series of questions:

- What are the facility's operating hours?
- When are no staff in the facility?
- How is the lighting currently controlled?

Through these questions, a plan can be built around the use and control of lighting.

A plan may involve a number of solutions. These solutions can be as simple as having the last person out turn off the lights or the decision may be made to install new fixtures. Every organization and every building is different. What may work or make sense for one location may not apply in another, even if the buildings are next to one another. Building use, budget, occupancy, and design are some of the many influencing factors in what can be done.

Requirements

Below is a list of some items you may want to have when creating your plan.

- There are four occupancy schedules to keep in mind. There may be overlap between schedules.

  - Operating schedule – This is the operating hours the facility is open to the public
  - Employee schedule – This is the hours that staff actively work in the spaces
  - Cleaning schedule – This is the schedule the cleaning staff follow
  - Unoccupied hours – When no staff or patrons are in the building
- If possible, locate a lighting control schedule if one exists. This may be included in the electrical series of the building drawings.
- Locate a copy of your electrical bill to determine your electrical cost per kilowatt hour (kWh).
- Use the lighting calculation sheets included in this guide to determine your current lighting costs and use the same sheets to plan alternative lighting methods.
- If necessary, building plans may be needed to track lighting, locate switches, and identify emergency lights in the facility.
- If you are unfamiliar with the difference in types of lighting, see the attached lighting guide.

Determine Goals

Reducing lighting use can be achieved through multiple methods. Unfortunately, establishing a predetermined goal may eliminate a potentially better solution. Starting the process with an open mind and no preconceived conclusion may yield better results than previous expectations.

Criteria/Variables That Impact Potential

- Replace bulbs – One of the least costly actions is replacing/swapping the bulbs inside the light fixtures with more energy efficient bulbs and/or those that emit light in less harmful ways.
- Replace light fixtures – In some cases the bulbs cannot be swapped out or it may be more cost effective (due to replacement bulb cost) to replace the light fixture.
- Add switches – Some spaces are designed where one master switch controls a majority of the lights. In some cases, sub-switches may be installed to break down less used sections and turn off the lights in these areas.
- Add motion sensors – There may be trouble spaces where light switches cannot be accessed or located; lights in an area may always be left on as a result. Installing motion sensors will add control to the space allowing lights to operate when the space is occupied and turn off when they are unoccupied.
- Adjust timers – Some lighting is controlled by timers. The original intent may have been to control/limit the lighting in the space, however over time the timers may have been adjusted, schedules may have changed, or certain timers may have malfunctioned or become inoperable. As a result, some lights may remain on during unoccupied hours. These timers can be adjusted, repaired, or replaced to account for the current operating schedule.
- Reduce lights – There are required light levels for some work areas. Sometimes these areas have more lights operating than are needed or wanted. It may be possible to remove or turn off these lights to eliminate waste. For storage environments, consider which lights, and at what intensity, are necessary for collection access.

- Reduce/eliminate outside light- Light coming in from windows and skylights should be mitigated through the use of shades (of various degrees of transparency or blackout) or filters to remove UV and visible light. It is important to be sure that during the different times of day, as the light moves throughout the room, the intensity on objects remains within acceptable parameters.

Start with Locations

- Knowing when specific locations in the facility are occupied will help inform when developing a lighting schedule.
- Start by looking at a map of the facility and identify normally unoccupied areas.
    - These may be storage rooms, collection spaces, galleries, workspaces, or laboratories, among others.
- If a space is normally unoccupied, look at the lighting controls for the spaces.
    - Are they normally left on?
    - Are they always off?
- Determine if these spaces may qualify for better lighting control.
    - Should motion sensors be installed to turn off lights when the space is unoccupied?
- In the case of lack of funding to install new lighting controls, some institutions have employed last-out rules. In this case the last person out of the facility (custodial, security, supervisor) is responsible for ensuring all lights are off.

Determine Schedules

- To begin look at the operating schedule for your facility. This schedule is most likely shorter than the employee schedule.
    - Identify any spaces where light can be reduced when visitors are in the building.
- Collect an employee schedule.
    - This schedule should create a rough timeframe of what hours the facility is occupied by staff.
    - Due to some staff working odd hours this may be difficult to produce and may need to be estimated.
    - While some staff may be exceptions, there are many staff members who have set schedules and lighting in their area or department can be reduced at a certain time.
    - Lighting schedules should be set for the majority, with localized control for exceptions.
- Look into the schedule for the cleaning staff or after hours staff, if any.
    - Not all facilities have a cleaning or after hours staff.

        - From the schedules determine the spaces where lighting hours can be adjusted.
        - Use the schedule that was created to readjust lighting timers if you have them.
        - Use the lighting schedule to create a potential list of spaces to check for lighting shutdowns during a walk-through.
            - Walkthroughs should be conducted during operating hours, during normal staff hours, and later at night when the building is mostly unoccupied.

Perform Test Calculations

Light reduction that involves the replacement of light bulbs or fixtures should be evaluated based on the calculated and modeled savings.

- Use the attached sheet to calculate the estimated daily light usage for your space/facility.
- Use this information to calculate the weekly/yearly energy consumption of current lights.
- You will need to know your electrical cost per kilowatt hour (kWh).
- Using the same calculations, you can figure out an estimated energy use of new lighting if you know what type of replacement bulbs you will be using.

NOTES:

- Be sure to know start and end dates to compare energy bills
- Be aware that changes in bulbs may also cause a change in space temperature
- Be sure staff are aware and informed of any changes to the lighting schedule
- Be sure staff are aware and informed if any work or changing of light fixtures is going to be done
- Be sure staff know of overrides or switches to turn lights on if needed

Implementation

Experiment with operation to determine whether control or changes can be maintained.

Evaluating Test Results

- An important technique to estimate effectiveness is by comparing energy bills before and after any changes were made.
- A second, less effective comparison method is to perform calculations of the pre-and post-conditions and compare the results.
- From a preservation perspective, the results can be calculated using measurements from a light meter

before and after changes, or, for a visual comparison, using ISO blue wool standards and tools such as the Canadian Conservation Institute (CCI)'s online light damage calculator.

REMINDERS FOR MAXIMIZING EFFECTIVENESS

- Be sure to fully inform staff.
- Verify the new lighting operation.
- Keep in mind that some lighting may be required for emergency egress, and will be on all the time. In these cases, additional protection for objects nearby can be provided by covering them or placing them in boxes.

Lighting Calculations

Lighting

Bulbs Per Fixture X Watts Per Bulb = Watts Per Fixture

Bulbs Per Fixture	Watts Per Bulb	Watts Per Fixture

Lighting

Watts Per Fixture X Number of Fixtures = Watts Sub-Total

Watts Per Fixture	Number of Fixtures	Watts Sub-Total

Weekly Lighting

Watts Sub-Total x Weekly Operating Days = Weekly Watts Sub-Total

Watts Sub-total	Weekly Operating Days	Weekly Watts Sub-total

Yearly Lighting

Watts Sub-Total x Yearly Operating Days = Yearly Watts Sub-Total

Watts Sub-total	Yearly Operating Days	Yearly Watts Sub-total

Cost to Operate Lighting

Watts Sub-Total x Average kWh Charge x .001 = Cost for Operating Lights

Watts Sub-total	Average kWh Charge	.001	Cost for Operating Lights

Fluorescent Lighting Annual Cost Comparison

BULB TYPE	T5	T5	T8	T12
Watts	18	28	32	34
Bulbs	2	2	4	4
Fixtures	100	100	100	100
Total Watts	3600	5600	12800	13600
Hours/Day	12	12	12	12
Days/Week	5	5	5	5
Weeks	52	52	52	52
Total Hours	3120	3120	3120	3120
Cost per kWh	$.12	$.12	$.12	$.12
Annual Cost	$1,347.84	$2,096.64	$4,792.32	$5,091.84
Savings vs. T12	73.5%	58.8%	5.9%	0%

Multiple Light Source Comparison

EFFICIENCY	Least			Most
BULB TYPE	STANDARD	HALOGEN	CFL	LED
Price (* = often subsidized)	very low	low	low to high*	medium
Watt comparison	60 watts	40-50 watts	13-15 watts	8-12.5 watts
Reaches full brightness instantly	YES	YES	NO	YES
Correlated color temperature, Kelvin	~2700	~2700	~2400-2900	~2600-3000
Light color appearance	warm-white	warm-white	varies	varies a lot
Stable color over time	YES	YES	NO	NO
Works with dimmers, sensors, and timers	YES	YES	RARELY	SOME
May emit RF and cause grid disturbance	NO	NO	YES	YES
Sensitive to heat	NO	NO	YES	YES
Sensitive to cold	NO	NO	YES	NO
Sensitive to frequent switching	NO	NO	YES	NO
Contains mercury	NO	NO	YES	NO
May leak UV-radiation	NO	NO	YES	NO
RATED LIFE	1 YEAR	1-2 YEARS	8-15 YEARS	15-25 YEARS

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About the Image Permanence Institute

IPI is a non-profit, research laboratory at the Rochester Institute of Technology (RIT) devoted to preservation research. Funding for IPI's research and outreach efforts has come primarily from the National Endowment for the Humanities, the Institute of Museum and Library Services, and The Andrew W. Mellon Foundation. IPI provides information, education opportunities, consulting, products, and testing services aimed to improve the preservation of cultural heritage collections worldwide.

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Next Steps

While this resource is a guide for mitigating risk when working to achieve sustainable preservation, each institution that chooses to use it will have to apply it to their own circumstances, and the outcomes will be as unique as each of our individual buildings and organizations. The concept of sustainable preservation has gone from the periphery of discussions to the mainstream, with numerous workshops, conference tracks, and symposia dedicated to the topic. We hope that this guide will help continue that conversation and inspire others to begin their own journey toward sustainable preservation.

Whether you choose to use this methodology to guide your institution's progress toward more sustainable preservation, or if you take a different approach to the same goal, please consider sharing your experience with your professional field. Success inspires others, and lessons learned provide critical perspective. Sustainability and sustainable preservation practices are goals that are larger than any single institution – our greatest advances and impacts can be achieved if we work to share these efforts among our allied cultural heritage professions.

Visit our website at www.imagepermanenceinstitute.org to learn more about IPI's research, education, and outreach activities.

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