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.

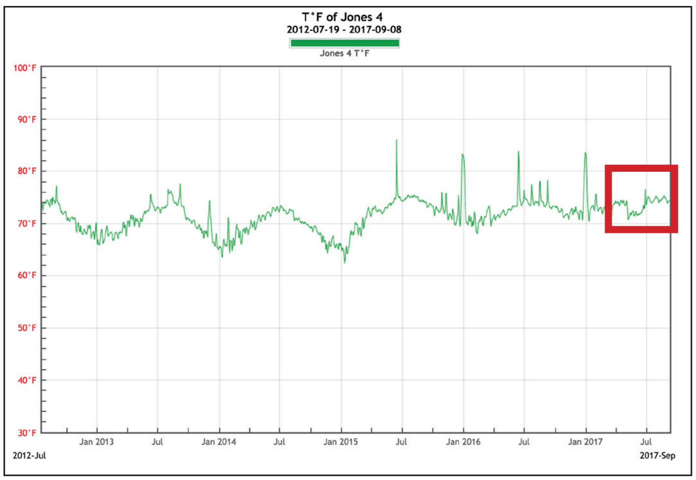
Chapter 6 in *IPI's Guide to Sustainable Preservation Practices for Managing Storage Environments* is an excellent introduction to data analysis for optimization; rather than repeat it here, this section will provide some additional practical guidelines, a few additional concepts for thinking about preservation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

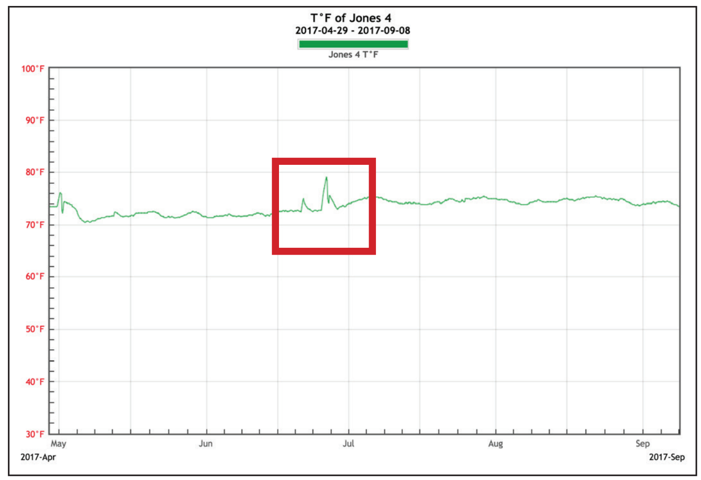
A few guidelines for making data analysis easier:

- 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

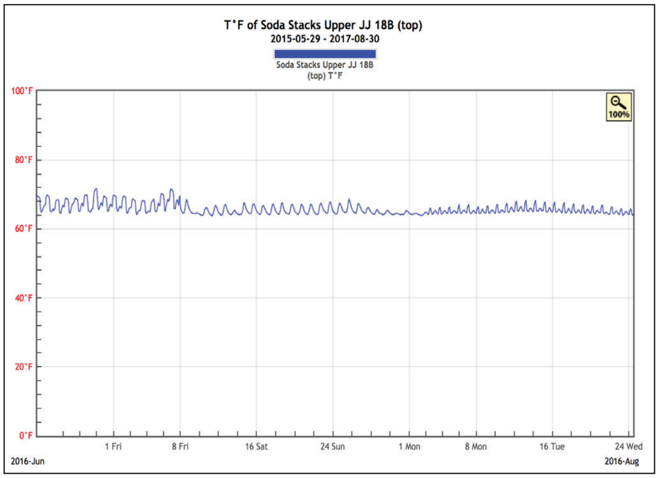
The process of working with graphs can often create interpretation issues for team members who have not worked with environmental data before. In most graphing packages that come with dataloggers, the temperature or relative humidity will be on the vertical, or Y-axis, while the horizontal X-axis will 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.

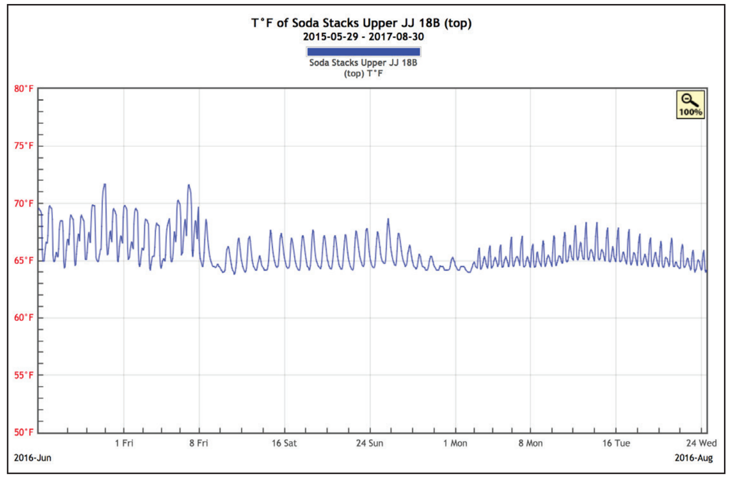




Together, the two graphs above illustrate the value in analyzing both extended and shorter amounts of data. The graph on the left represents over four years of environmental data. In this extended view, seasonal trends are visible, but a power outage that occurred on June 30, 2017 is not visible. In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

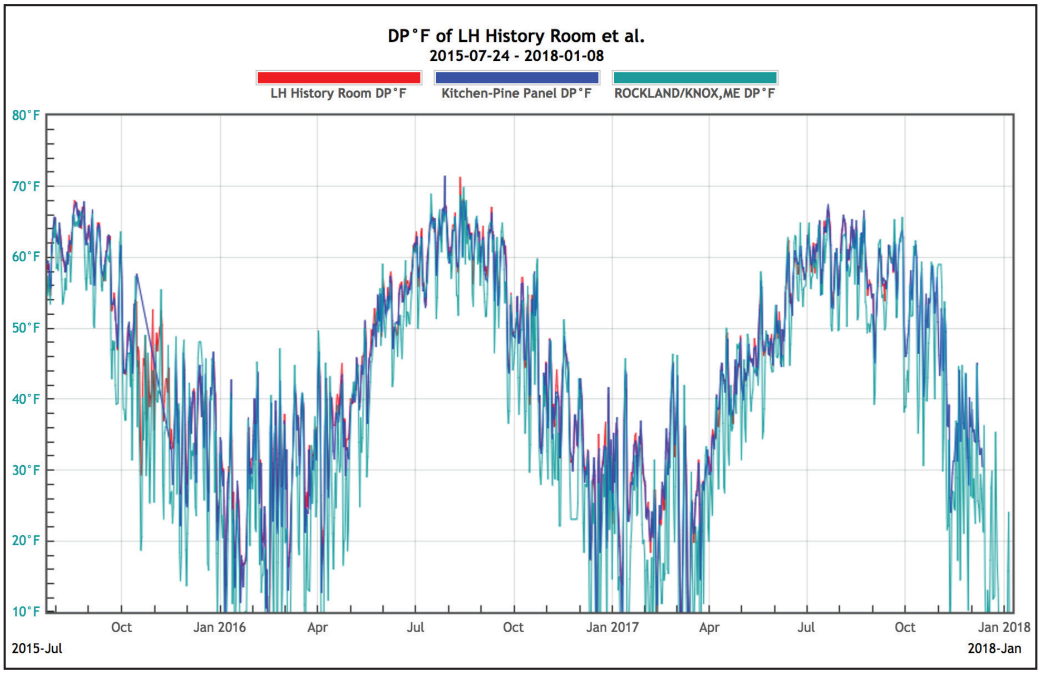
The dew point temperature is the temperature in the environment where the air is completely saturated with moisture – as the air cools below this temperature, moisture in the air will condense. It is a measure of the absolute amount of water in the air, and is what determines the type of environment 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).

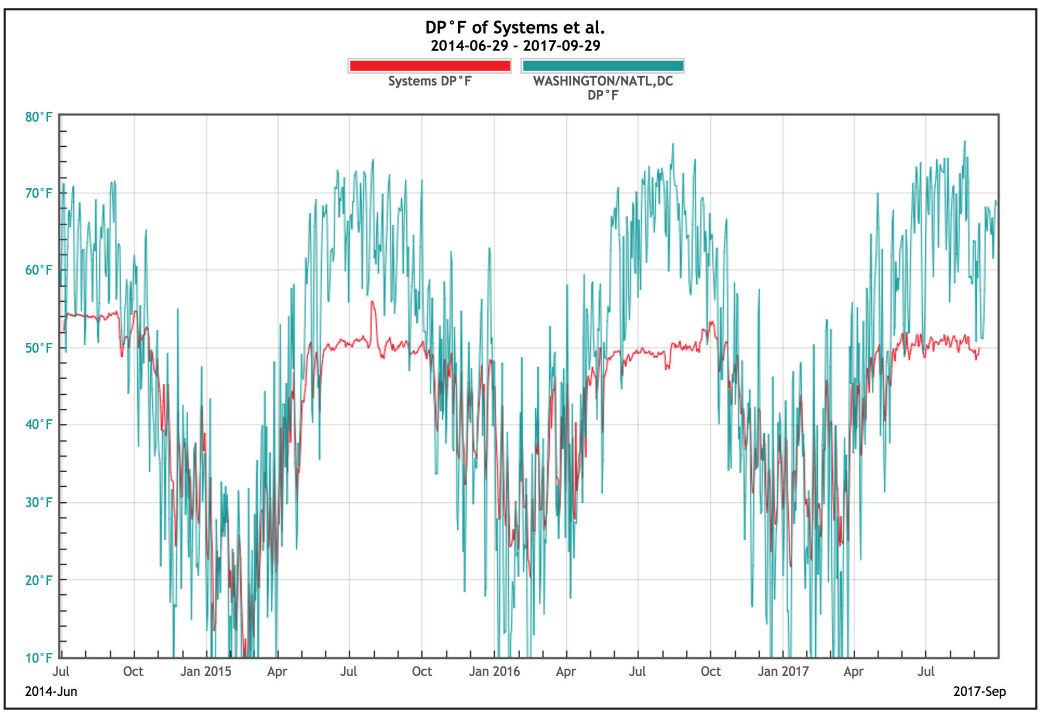
Having a lower dew point allows for temperatures to be lower while still maintaining appropriate relative humidity levels, which is critical for ensuring long-term preservation. Beyond the preservation implications, from a mechanical perspective, the ability to control dew point is often the limiting 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:

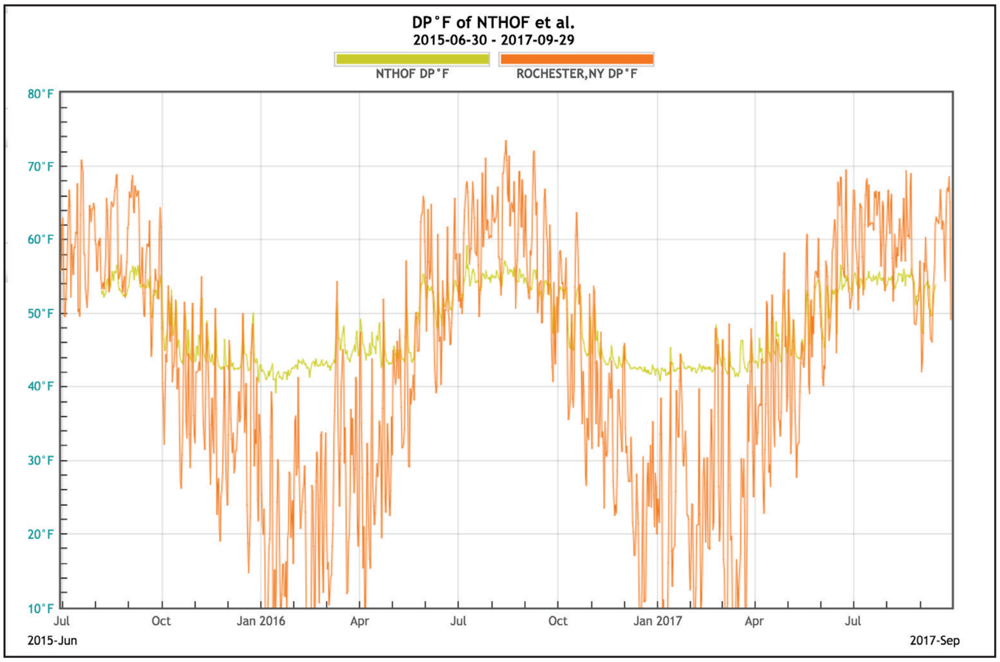
1. The influence of the outside environment on the collections environment – when comparing indoor and outdoor dew points, the closer together they are, the less moisture control is being performed (see graph on the following page). Buildings without mechanical systems will have indoor dew points very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