SECTION 1:
WHAT YOU NEED TO KNOW

DEFINE AN OPTIMAL AND SUSTAINABLE PRESERVATION ENVIRONMENT

Section One includes two chapters:

- Chapter 1: The Basic Elements of the Environment and Their Effect on Collection Materials
- Chapter 2: The Factors that Shape the Storage Environment

These chapters introduce the various elements that create the storage environment and the way that materials in the collection respond to those elements. With an understanding of these fundamentals it is possible to define an optimal and sustainable environment for the preservation of institutional collections.

Section Two – What You Need to Do – will cover activities involved in achieving an environment with the least risk to collections and the best energy savings possible.

1

CHAPTER 1:
The Basic Elements of the Environment and Their Effect on Material Decay

Long-term preservation of the collection materials requires an understanding of the elements that make up the environment (temperature, relative humidity, dew point), the elements that make up your collection (organic, inorganic, and composite materials), the basic modes of deterioration (chemical, biological and mechanical), and the basics of material decay (reacting to heat and moisture).

1A Environmental Basics – Defining Temperature, Relative Humidity, and Dew Point

While there are a number of factors that can be included in a broad concept of storage environment, this guidebook deals primarily with the environment. Light, air pollution, radiation, and vibration – when present – are important and deserving of attention. However, temperature and relative humidity are the most fundamental factors to consider in environmental management. They are always present and they have a direct affect on the rate of decay in nearly all materials. Research has also shown how important understanding the role of dew point is in managing the environment for preservation. (See Section 2, Chapter 5—Understand the Role of Dew Point).

Temperature

HEAT IS A FORM OF ENERGY THAT DRIVES CHEMICAL REACTIONS

Temperature is the measure of the motion of molecules in a material. As temperature increases the molecules move faster and collide with greater force, increasing the chances for a chemical reaction to occur. At higher temperatures, biological activity also increases as insects eat more and breed faster, and mold growth increases. This is why colder temperatures are often recommended for collection storage—cooler temperatures mean a slower rate of chemical decay. Not too cold, however—at low temperatures some materials contract and may become brittle.

Relative Humidity (RH)

REPRESENTS HOW SATURATED THE AIR IS WITH WATER VAPOR AND DETERMINES THE AMOUNT OF WATER CONTAINED WITHIN COLLECTION OBJECTS

Water vapor forces its way into and out of moisture absorbing materials until equilibrium – a balance between interior and exterior moisture levels – is established. Most organic and some inorganic materials are hygroscopic – they absorb and release water depending on the relative humidity of the surrounding air. As the RH in the space increases, objects absorb more water; as it decreases they release moisture. Mold growth can become a problem at 65% RH and above. At low humidity levels, wood and ivory will shrink, warp and crack; leather and photo emulsions will shrink, stiffen, crack and flake; paper, fibers and adhesives will desiccate.

IPI's Dew Point Calculator is available for free at:

http://www.dpcalc.org

You can explore various combinations of temperature, relative humidity, and dew point and compare the relative preservation quality of each environment.

Dew Point

A MEASURE OF THE ABSOLUTE AMOUNT OF WATER IN THE AIR

Dew point is also the temperature at which the air cannot hold all the moisture in it and water condenses. As air is circulated into and around a building, its absolute moisture content—and therefore its dew point—does not change unless it is humidified or dehumidified. In other words, unless the mechanical systems add or remove water from the air, the outdoor dew point and the indoor dew point will be the same.

Temperature, Relative Humidity, and Dew Point are Interrelated Variables

The dew point determines what combinations of temperature and RH will be possible in the storage environment. At a constant dew point, when the temperature goes up, the RH goes down and when the temperature goes down, the RH goes up. Therefore, the dew point is responsible for determining which temperature setting will give you which RH. Institutions that try to improve conditions by lowering storage temperatures without carefully watching the resulting RH may find that the moisture level is much too high for safe storage of vulnerable collections. You can explore this relationship using http://www.dpcalc.org.

1B Collection Basics – Defining Basic Material Types

Most of us look at the collections in our care in terms of object type—paintings, furniture, documents and manuscripts, fossils, etc. When managing the environment for preservation, it is important to understand the collections as materials, as the substance that they are made from. This perspective makes it easier to understand the reaction of various collection types to the storage environment.

Material Types

Museum objects are often divided into three material-type categories: organic, inorganic, and composite. Understanding the properties of each of the materials in these categories will help you understand how they react to the environment.

ORGANIC MATERIALS

Organic objects are made from materials that were once living — plants or animals. These materials include wood, paper, textiles, leather and skins, horn, bone and ivory, grasses and bark, lacquers and waxes, plastics, some pigments, shell, and biological natural history specimens. Organic materials are processed in a multitude of ways to produce the objects that come into your collections.

Organic materials share the following common characteristics:

- They contain the element carbon
- They are combustible
- They are sensitive to light
- They are a source of food for mold, insects, and vermin
- They are made of complicated molecular structures that are susceptible to deterioration from extremes and changes in relative humidity and temperature
- They absorb water from and emit water to the surrounding air in an ongoing attempt to reach an equilibrium (hygroscopic)

INORGANIC MATERIALS

Inorganic objects have a geological origin. Inorganic materials include metals, ceramics, glass, stone, minerals, and some pigments. As with organic objects, inorganic materials are processed in a variety of ways to produce the objects found in your collections.

Inorganic materials share the following common characteristics:

- They have undergone extreme pressure or heat
- They are usually not combustible at normal temperature
- They can react with the environment to change their chemical structure (for example, corrosion or dissolution of constituents)
- They may be porous (ceramics and stone) and will absorb contaminants (for example, water, salts, pollution, and acids)
- They are not sensitive to light, except for certain types of glass and pigments

COMPOSITE OBJECTS

Composite or mixed media objects are made up of two or more materials. For example, a painting may be made of a wood frame and stretcher, a canvas support, a variety of pigments of organic and inorganic origin, and a coating over the paint. A book is a composite of several materials such as paper, ink, leather, thread, and glue.

Depending on their material makeup, composite objects may have characteristics of both organic and inorganic objects. The individual materials in the object will react with the environment in different ways. Also, different materials may react in opposition to each other, setting up physical stress or causing chemical interactions that cause deterioration.

1C Deterioration Basics – Defining Types of Environmentally-Induced Decay

Deterioration is a natural process by which an object reaches a state of equilibrium with its immediate environment. The primary types of deterioration detailed here include chemical decay or natural aging, biological deterioration, and mechanical or physical decay. Deterioration is inevitable, but the rate of physical and chemical change in an object can be slowed if the storage environment is properly managed.

Chemical Decay – a chemical reaction that causes changes in an object at the atomic and molecular level

A wide variety of decay manifestations in collection objects are caused by chemical reactions. Examples of chemical decay include metal corrosion, deterioration of pigments, staining by acidic materials, and embrittlement of pulp papers and textiles. Both moisture and temperature play a role in chemical decay. For organic materials such as paper, vellum, wood, textiles and plastics, chemical decay is ongoing and spontaneous. For this reason, chemical decay is sometimes referred to as "natural aging". Preservation benefits accrue as objects become cooler and drier because decreased thermal energy slows the rate of chemical reactions. Dry conditions starve chemical reactions of the moisture needed for the reactions to take place.

Corrosion is a form of chemical decay found most commonly in metals. Corrosion results from high humidity, high temperature, and atmospheric pollutants. Examples of corrosion include silver tarnishing and rust damage. Corrosion can be concentrated to form a pit or crack, or may extend across a wide area. Corrosion is primarily the result of moisture in the air, and begins at relative humidity levels of about 55% or greater. However, the presence of pollution, dust, salts, oils or active corrosion can allow metal corrosion to occur at lower humidity levels.

Biological Decay – caused by the attack of biological organisms

Biological decay is driven by heat and especially by moisture. Organic materials are particularly susceptible. In practice, mold and insects pose the most acute biological preservation risks. Mold spores are always present in the atmosphere and just require a sustained high RH for a certain period of time to propagate. Active mold produces enzymes that can digest organic materials such as paper and textiles, weakening or destroying them. Colorful blooms can cause stains that cannot be removed. Generally, maintaining RH conditions below 65% eliminates any risk from mold growth. Insect infestations, which can result in damage or loss due to feeding by insects or their larvae, are minimized by keeping RH below 50% and temperatures cool.

Mechanical Decay – a change in the physical structure of an object

Mechanical decay includes softening of plastics and waxes, cracking and buckling of wood, warping, and delamination. This type of decay can be caused by physical force or mishandling, but may also be the result of changes in the environment that lead to physical stresses in an object. Environmentally-induced mechanical decay is primarily driven by extremes of RH, although temperature extremes can affect the degree of risk if prevailing conditions are cold enough to cause brittleness or dry enough to cause cracking.

Estimating the degree of risk of mechanical decay from improper RH conditions is difficult to generalize because the construction details of composite objects have a strong influence on their behavior. Various materials will respond differently and cause stress between components of an object. Excessive dampness can result in differential expansion, sagging, warping, and permanent deformation. Excessive dryness leads to contraction, brittleness, cracking and tearing. Risk also results from repeated changes in moisture content that cause slow progression of micro-cracks and other forms of "fatigue" in materials.

1D Risks & Benefits: Understanding How the Environment Determines the Rate of Material Decay

The preservation quality of an environment is best judged in terms of relative risks and benefits to the collections in the space. Because decay occurs through different mechanisms – chemical, mechanical, and biological – conditions that bring benefits for one decay mechanism may bring increased risk with another. For example, extreme dryness will eliminate corrosion risk in metals and slow the natural aging rate in organic materials. However, for some objects, such as vellum-bound books, dryness presents an unacceptable risk of shrinkage and brittleness, especially when handled. You'll need to find the right balance of risk and benefit for the materials in your collection.

The risks to collections from theft, fire, flood, or other catastrophic events are always considered and steps are put into place to protect and insure against these risks. Shouldn't the risk to collections from the storage environment demand the same consideration?

The Effect of Temperature on Material Decay

- At high temperatures (generally above 75°F) chemical reactions increase and the rate of "natural aging" increase. Magnetic media, plastics, film, leather, rubber, dyes, and acidic paper are particularly vulnerable. Watch for deformation, sagging, melting, stickiness, and adhesive failure.
    - Magnetic media may disintegrate or be unplayable.
    - Color prints may fade, other organic materials may discolor.
    - Cellulose nitrate will disintegrate.
    - Acetate film and early plastics will shrink, crack, and distort.
    - Elastic polymers like foam and rubber become brittle or sticky.
    - Acidic paper will become brittle.
- Biological activity increases at warmer temperatures—insects will eat more and breed faster, mold will grow faster within certain temperature ranges.
- In general low temperatures are good for preservation, provided that they don't result in dangerously high RH.
- Some materials are sensitive to low temperatures (below 50°F), particularly polymers found in modern paints and coatings, vulnerable rubber and plastic objects. Temperatures that are too low can cause desiccation, which results in fractures in paints, adhesives, and other polymers.
- Wide and frequent fluctuations in temperature can cause fractures and delamination in brittle, solid materials. Furniture, ivory, and oil paintings are particularly vulnerable.

The Effect of Relative Humidity on Material Decay

- Dampness (relative humidity over 65%) can result in mold, metal corrosion, and dye bleed in vulnerable collections. High humidity also causes swelling and warping of wood and ivory, buckling of paper, softening of adhesives, and an increase in biological activity.
- Relative humidity above 0% supports hydrolysis that gradually disintegrates and discolors organic materials, especially materials that are chemically unstable such as pulp paper and magnetic media.
- Dryness (low relative humidity) will cause organic materials to shrink, warp and crack; papers and textiles can become brittle.
- Fluctuating RH will shrink and swell unconstrained organic materials, crush or fracture constrained organic materials, cause layered organic materials to delaminate and/or buckle, and loosen joints in organic components.

When Do Collections Feel Changes in the Environment?

The next issue to consider is how long it takes for collection objects to equilibrate (or adjust) to any changes in the environment. Do objects react differently to changes in temperature than they do to changes in relative humidity? What factors determine the rate of equilibration?

THERMAL EQUILIBRATION – ADJUSTING TO TEMPERATURE CHANGE

Material response to changes in temperature, called thermal equilibration, occurs relatively quickly compared to the response to changes in RH. **Most materials will adjust to the temperature of a new environment in a matter of hours** (See Section 4 - Annotated Bibliography: Material Response and Behavior, p.84 for more information). When researchers at IPI exposed a variety of photographic materials to temperature changes, they found that most fully equilibrated to the new temperature conditions within 6 to 12 hours. Adjustment time varied according to the material and its configuration. Despite these differences, all the tested materials—motion-picture film, acetate sheet films, and resin-coated photographic prints—demonstrated a relatively fast rate of thermal equilibration.

The time needed to adjust to a new temperature condition is influenced by the amount of exposed surface area and the thermal mass of the object. Objects with a large percentage of their surface area exposed to a new environmental condition will equilibrate faster than objects with less. In other words, a single object on a shelf will equilibrate faster than an object in the middle of a stack of objects. The thermal mass of the object has a similar effect on equilibration time. The greater the thermal mass, the more time it takes for energy to penetrate to the object's core. For most collection objects however, thermal equilibration requires just a few hours.

Because enclosures and housings offer physical protection for the object, you might assume that the enclosures also protect the objects from changes in temperature. However, while some enclosures may act as a moisture barrier, research shows that enclosures do not significantly block the transfer of heat or reduce the time needed to adjust to new temperature conditions. Studies also show that the extent of the temperature change does not alter the time needed for full thermal equilibration. Researchers at IPI enclosed a stack of photographic prints in a cardboard box. The stack was then exposed to three different temperature changes: raised from 3°F to 70°F; raised from 41°F to 70°F; and cooled from 122°F to 70°F. In each case, it took the stack approximately five hours to equilibrate to the new temperature. Although the first test group had to warm up significantly more (67°) than the second group (29°), the time to reach equilibration was the same. The direction of temperature change did not significantly alter the time needed for equilibration time either—when the stack was cooled from 122°F to 70°F the time to equilibrate was the same.

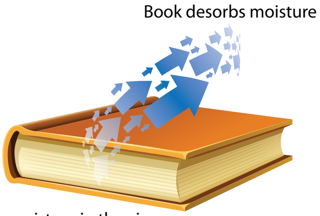
It is important to remember that the amount of heat in the environment is usually more significant to preservation than the fluctuations in temperature. The higher the temperature, the faster chemical reactions will occur; the lower the temperature, the slower chemical reactions will occur.

CONCLUSION: Sustained high temperatures have a much more significant impact on the stability of collection materials than do temporary spikes or wide fluctuations of temperature.

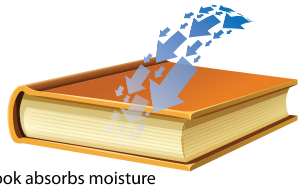
MOISTURE EQUILIBRATION – ADJUSTING TO CHANGES IN RELATIVE HUMIDITY

Material response to changes in relative humidity, called moisture equilibration, occurs relatively slowly compared to the response to changes in temperature. **All of the materials tested by IPI (without enclosures) reached moisture equilibration in a matter of days or weeks, as opposed to hours for thermal equilibration**. The process of moisture equilibration is more complex than that of thermal equilibration. Several variables determine the length of time it takes an object to equilibrate—including its size, the amount of surface exposure, object enclosures and temperature. Finally, there is more variation in the capacity of individual objects to control moisture equilibration than thermal equilibration.

Only hygroscopic materials—organic materials that naturally contain water—are susceptible to moisture equilibration. These materials absorb or release water to equilibrate with the relative humidity of the environment. Non-hygroscopic materials are not absorbent by nature and have no moisture to release. They therefore don't equilibrate with changes in the environment's moisture, however they may be affected by moisture in other ways, such as corrosion of metal.



As the moisture content of the air increases, the material begins to absorb the increased moisture. The moisture travels from the outside of the object inward, affecting the edges and the top of the object before reaching the core. When the relative humidity of the environment decreases, the material releases moisture into the environment in order to reach a balance. The moisture travels from the inside of the object outward towards the surface. This exchange of moisture is continuous until the object has reached moisture equilibrium with the environment.



Moisture equilibrium is not attained instantly. It takes time for the object to absorb or release the appropriate amount of moisture. Only if the new humidity conditions last long enough will the entire object reach complete moisture equilibrium with the environment. Attaining complete equilibrium with the environment is referred to as 100% equilibration. If an object has not had time to completely equilibrate to a new condition, it may only be 25% or 50% equilibrated.

To see how objects respond when they are freely exposed to humidity changes, researchers at IPI exposed a variety of materials without enclosures to two different humidity scenarios at a constant temperature 70°F:

- a onetime change from 20% to 50% RH, to see how fast the materials absorb moisture
- a onetime change from 50% to 20% RH, to see how fast the materials desorb moisture

The materials used included 1" magnetic tape, ¾" magnetic tape, a 35mm film roll, a 16mm film roll, a single book, a book in the middle of a group, a stack of papers, and a stack of mounted photographs.

- The fastest equilibration time was seen when the ¾" magnetic tape was exposed to drier conditions. It took less than half a day to release enough moisture to reach 50% equilibration.
- The longest equilibration time was seen when the stack of mounted photographs was exposed to drier conditions. It took 15 days to release enough moisture to reach 50% equilibration.

Because the rate of equilibration drastically slows down as it approaches 100%, we can't assume that 100% equilibration will be reached in double the time for 50% equilibration. However, we can use the time to 50% equilibration as a benchmark to gauge how slowly equilibration can occur.

A sudden or short term fluctuation of relative humidity does not affect the moisture content of objects in the space immediately. In fact, if the increase is temporary, the bulk of the object may not "feel" the change at all.

IPI's research showed that:

- A hardcover book alone on an open, wire shelf, with its surface exposed to the environment on all sides, took two days of sustained humidity conditions to reach just 50% equilibration.
- A hardcover book stacked between other books on a shelf will equilibrate to a 20% change in RH in about one month.

CONCLUSION: Periods of sustained high humidity in the summer and sustained low humidity in the winter are much more significant in terms of preservation than sudden or short term fluctuations in RH.