CHAPTER 4: MUSEUM COLLECTIONS ENVIRONMENT

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A. Overview

1. *What information is included in this chapter?*

This chapter provides information on how to protect museum collections from deterioration caused by interaction with the surrounding environment. From the moment an object is created, it begins to deteriorate. The factors that can cause or accelerate deterioration are called "agents of deterioration." See Chapter 3, Section A, 1 for a more complete discussion. Environmental agents of deterioration discussed in this chapter are:

- temperature
- relative humidity (RH)
- light
- air pollution

Basic information about these agents of deterioration is provided here to enable you to recognize how they affect collections, how to monitor them, analyze their potential impact, and how to control your collections environment. Guidance is provided on how to identify, eliminate, block, and/or minimize the negative effects of these agents of deterioration. Information on collection environment, building basics, and on non-mechanical methods to control your collections environment is provided. The chapter provides recommendations for temperature and relative humidity as well as lighting standards.

For more information, see the following sections:

E.4, What is the recommended temperature set point and fluctuation range for general collections?

F.6, What is the recommended RH set point and fluctuation range for general collections?

I.4, What are light standards?

Every park with collections must establish an environmental monitoring and control strategy for collections in storage and on exhibit. See Director's Order 24, 4.3.12 Collection Condition which states, "Monitor and record information about the environment in spaces housing collections and manage the environment to maximize preservation.''

To promote long term collections preservation, make sure that all staff that interact with the collection recognize the importance of maintaining a suitable environment. See Chapter 7, Museum Collection Storage and Appendix T, Curatorial Care of Biological Collections for additional information.

Note: Guidance in this chapter applies to all collections housed or exhibited in purpose-built, adapted structures, and furnished historic structures. Information that applies only to furnished historic structures is specifically noted.

2. Why is it important to monitor, analyze, and control the collections environment?

Monitoring, recording and analyzing climate data allows you to evaluate the risks posed to collections, adjust controls to better maintain a suitable and stable environment, and take steps to minimize damage from temperature (and variations in temperature), relative humidity (and variations in relative humidity), and light and air pollution. This, together with good collections management practices outlined in this chapter and *Handbook*, will enhance object integrity and preservation and reduce the need for invasive and costly conservation. It is also important to recognize the need to reduce energy consumption without compromising the integrity of the collections.

3. What agents of deterioration affect the museum environment?

The agents of deterioration discussed here are environmental forces that act on objects causing chemical, physical, and biological damage. ***The damage is cumulative and causes irreversible losses to collections.*** These agents of deterioration are:

Incorrect temperature that can be:

too high causing gradual disintegration, discoloration, expansion of certain materials and increased pest activity. For more information, see Section B.2, What types of materials are in the collection and how do they respond to environmental changes?

too low causing desiccation and embrittlement which results in fracturing of paints, adhesives, and other polymers.

fluctuating potentially causing delamination and fractures in materials due to the dissimilar expansive nature of the laminates.

See Section E.2 How does temperature affect objects?

Incorrect relative humidity can be:

too damp (over 65%) causing mold growth and/or swelling and deformation of hygroscopic (typically organic) materials, corrosion of metals, increased pest activity.

too dry causing desiccation of hygroscopic materials resulting in shrinkage and cracking in certain materials such as ivory, teeth or wood, and dehydration of some minerals.
above or below a critical value causing hydration/dehydration of some

minerals.

fluctuating causing cycles of shrinkage and swelling organic materials. If the material is constrained, this could potentially result in deformation or/and fractures, causing layered hygroscopic materials to delaminate and/or buckle, and loosening of joints of organic components.

See Section F.5, What deterioration is caused by incorrect relative humidity?

Light (radiation), both naturally occuring and artificial, is composed of wavelengths, including:

ultraviolet radiation (UV) that causes weakening, chalking darkening, yellowing and/or disintegration of the outer layer of organic materials and some dyed or colored inorganic materials.

visible light that fades (bleaches) or darkens the outer layer of paints, inks, dyes, wood, textiles, photos, plastics, and other organic and inorganic materials.

infrared radiation (IR) that heats the surfaces of objects causing disintegration and discoloration in materials (with the same impact as that from high temperature) and desiccation of hygroscopic materials.

See Section I for detailed information on light.

Contaminants or particulate and gaseous air pollutants that disintegrate, discolor, or corrode all types of objects, especially reactive (such as metals) and porous materials. Contaminants include:

gases, pollutants such as hydrogen sulfide, nitrogen dioxide, sulfur dioxide, formic and acetic acids, peroxides and ozone.

liquids such as plasticizers that ooze from adhesives and some plastics, and grease from human hands.

solids such as dust that can abrade surfaces and provide nutrients for pests, salt that corrodes metals.

See Section K for detailed information on pollution.

4. What are the steps to protect collections from environmental agents of deterioration?

Take the steps below to develop a strategy to protect your collections in storage or on exhibit.

- **Know the collection**

– Become familiar with objects in your collection, the materials they are made of, and how they were made and used.

– Identify sensitve objects with special environmental requirements or that have previous damage and how the damage was caused.

– Monitor object condition. Develop a "critical eye" to evaluate object condition and identify reasons for condition changes.

– Be aware that objects will have acclimatized to the local environment.

– Seek visual cues to the agents of deterioration such as condensation on cold surfaces, water stains on ceilings or walls, and fading of organic materials such as textiles or botanical specimens.

- **Know the structure and the building envelope housing the collection**

  Understand the building in which collections are kept: its location and orientation to the sun, its surroundings, the local climate, the building envelope (materials used, insulation, openings such as windows and doors, attic, basement, roof), the interior (floor plans, furniture, mechanical systems if present, etc.). For more information, see Section C, Building Basics for Collections.

- **Know your local climate and its impact on the building envelope and on the collections environment**

  Monitor exterior climate conditions and seasonal fluctuations and how they affect the building envelope and in turn, the interior spaces housing the collections. Track and evaluate climate data for long term trends. See Section C.4, How do structures respond to the local climate?

- **Maintain a stable climate and minimize fluctuations**

  Determine the temperature and RH set point and a maximum and minimum fluctuation range that accommodates the needs of most of the objects in your collection and that takes the building housing the collection and local climate into account.

  For more information on how to determine these optimum set points, see Section E. 4, What is the recommended temperature range for general collections?, F.6, What is the recommended RH set point and fluctuation range for general collections? and Section H, Methods of Controlling Temperature and Relative Humidity and consult with your regional curator and a conservator.

- **Containerize the collection**

– Organize the collection by material type and group sensitive or vulnerable materials to provide special environmental conditions efficiently.

– House objects in well constructed and sealed steel cabinets to buffer against climate fluctuations and minimize exposure to light. See Chapter 7, Museum Collection Storage.

– Enclose open shelving or large objects with muslin or polyethylene sheets to buffer or "containerize" collections.

– House sensitive or vulnerable materials separately to provide special environmental conditions efficiently. Create microclimates for instable materials.

For more information, see Section H. 2, How do sealed cabinets help stabilize the collections environment? and Chapter 7, A.2, What is a multi-layered collection storage system and how does it protect my collection?

- **Avoid the agents of deterioration in areas housing collections**

– Locate your collection storage away from the flood plain of a river, stream, and lake or seashore.

– Build or modify the storage facility so that is properly insulated, has no windows (i.e., no natural light) in collections areas, and that can readily maintain the selected temperature and RH set points.

– Build or modify exhibit spaces to block UV and exposure to daylight (radiation).

– Do not house collections in basements or attics.

- **Block agents of deterioration when you cannot avoid them**

– Be pro-active in blocking agents of deterioration by identifying problem areas and taking appropriate action.

You should:

– Cover windows in re-purposed buildings with solid material to block daylight (natural light) and minimize temperature and RH fluctuations.

– Install UV filtering materials on windows and fluorescent lights in furnished historic structures and visitor centers housing collections.

– Fill cracks and gaps in the building envelope, including around doors and windows, to better insulate the interior from the outside environment and block pest entry.

- **Test the methods used to block the agents of deterioration by monitoring**.

– Monitor RH and temperature to find out if your climate control system is working properly and if your mediation methods are effective.

– Monitor the light levels such as UV in exhibit areas.

– Monitor objects for changes that correlate to agents of deterioration and keep written documention.

For more information, see Section H, Methods of Controlling Temperature and Humidity.

- **Evaluate and respond to the environmental information gathered**

Monitoring is a waste of time if you do not evaluate and use the information to determine which mediation methods are working and which need to be modified. Adjust your environmental management practice accordingly in consultation with the park facilities manager and a conservator.

For more information on blocking and controlling agents of deterioration, see Section H. Methods of Controlling Temperature and Relative Humidity.

- **Establish a preventive conservation strategy**

Make informed decisions by ongoing monitoring and evaluation of the collections environment.

– Create an environment that mitigates agents of deterioration using effective and practical preventive measures.

– Carry out preventive conservation systematically to minimize damage from the agents of deterioration once objects enter the collection and to keep conservation treatment at a minimum.

– Continuously monitor, evaluate, and respond to environmental information and adjust your environmental practices when necessary.

– Develop a treatment plan to address specific problem objects in your collection. Objects may enter your museum damaged and deteriorated from use and exposure. Because of their history, even in the best museum environment, some objects will need treatment.

For more information, see Section H, Methods of Controlling Temperature and Relative Humidity and Section J, Monitoring and Controlling Light.

B. Collections Environment Basics

1. What variables should be taken into account when determining the optimal collections environment?

NPS collections are located throughout the U.S. in a wide range of climate zones. They include different material types that are housed in variety of structures. Consider the variables noted below when establishing an optimal environment for your collection.

- **Types of material in the collection**. Certain materials are more vulnerable or unstable than others. They may have different temperature and RH requirements and are or may be more sensitive to environmental fluctuations. House these objects separately. Handle objects composed of more than one material on a case-by-case basis. See Section E for information on temperature and F.8 for RH recommendations for sensitive materials.

- **Type of structure housing the collection.** Various structures, such as purpose built, adapted, and historic structures are capable of sustaining different temperature and RH ranges. The nature of building type and materials, as well as openings such as windows determine how effective a buffer the structure or building envelope provides the collections from the exterior climate, including light penetration.

- **Local climate.** Local climate and seasonal fluctuations impact the building envelope, and in turn, the interior building climate. Work with the facilities manager to ensure that the building envelope mediates against temperature and RH extremes and fluctuations, and light penetration. For historic structures, consult a historic architect to ensure that this can be done without damage to the historic fabric.

- **Interior collections environment.** Temperature, RH, dew point (see Section F.1 for a definition of dew point), light and contaminants are critical components of the collections environment within the area housing the collection. They influence the physical, chemical, and biological processes that cause deterioration of organic and inorganic materials.

2. What types of materials are in the collection and how do they respond to environmental

Materials respond differently to environmental changes. Cultural and natural history object vulnerabilities are determined by their physical and chemical composition and can be divided into three categories: organic, inorganic, and composite. Become familiar with the *changes?*

properties of materials in all categories in order to understand their vulnerabilities and environmental requirements.

Organic objects: Objects that are derived from once living plants or animals include wood, paper, textiles, leather, skin, horn, bone, teeth, ivory, grasses and bark, lacquers and waxes, plastics, some pigments, shell, certain fossils that are not fully lithified (combination of organic and inorganic materials), and biological specimens. All organic materials share certain characteristics and vulnerabilities. They:

- contain the element carbon
- are made of complicated molecular structures that are susceptible to deterioration from extremes and changes in RH and temperature
- may be hygroscopic, that is, they absorb water from and emit water to the surrounding air in an ongoing attempt to reach an equilibrium
- are sensitive to light
- are a source of food for mold, insects, rodents and other museum pests

Inorganic objects: Objects that have a mineral origin include metals, ceramics, glass, stone, minerals, fully lithified fossils (when permineralized), and some pigments. Inorganic objects share certain characteristics and vulnerabilities. They:

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

Composite objects: Mixed media objects are made up of two or more materials. They may include both organic and inorganic materials and may have the characteristics of both and so may react with the environment in different ways and rates. Materials may react in opposition to each other, creating physical stress and causing chemical interactions that lead to deterioration. Examples include books (paper, ink, leather, thread, and glue), paintings (wooden frame and stretcher, canvas, organic and inorganic pigments), musical instruments (wood, rawhide, paint) and jewelry (metals, stones, minerals, feathers, etc.).

Note: Inappropriate temperature and RH levels (too high and too low) as well as large and prolonged deviations beyond the acceptable fluctuation range can cause damage and deterioration to objects. It takes time for objects made from hygroscopic materials to adjust to changes in RH, depending on the type and thickness of the material used, construction and finishes. This time can range between a few hours (sheet of paper) to several weeks (wooden sculpture). Therefore, short term "spikes" can often be tolerated. In situations in which the RH changes quickly to either extreme (too high or too low) and this change remains in place for a time period long enough for the material to fully respond, damage may result. Constrained materials are at greater risk of damage then unconstrained materials.

These fluctuations accelerate and/or cause chemical, physical and biological processes that lead to object deterioration. This includes cracking, corrosion, fading of pigments and dyes, and mold growth. Exposure to light and pollutants exacerbates this deterioration.

Similarly, thin or constrained organic objects with a large surface area are particularly vulnerable to rapid and extreme fluctuations in temperature and RH. These include film-based materials, ivory, teeth, pyritic specimens, shell, as well as objects with thin skinned and wood veneers. House these materials separately in enclosed containers or in separate climate zones within the structure.

3. What is the appropriate environment for collection preservation?

A moderate climate that avoids extreme temperature and RH fluctuations and that excludes daylight and/or filters out ultraviolet and infrared radiation and air pollution provides the appropriate environment for collection preservation.

Design or adapt the structure or space housing the collections to maintain an optimum collections environment.

In storage areas exclude daylight (natural light), and UV and IR and use artificial lighting that does not emit UV or IR.

In furnished historic structures, galleries and visitor centers, exclude or block daylight and exclude, block or filter visible light in furnished historic structures and visitor centers. Keep artificial light levels low and free of UV and IR. See Section J, Monitoring and Controlling Light for more information.

Housing objects in well-sealed exhibit cases and steel storage cabinets enables you to provide an environment that buffers against climate extremes and minimizes exposure to light. See Figure 4.1, RH Readings Taken Outdoors, Within a Storage Space, and Inside a Cabinet within the Storage Space Over One Month.

House objects separately that require different RH and/or temperature levels that could be harmful or too difficult to maintain for the general collection. Note: Do not open cabinets during high humidity events to prevent trapping moisture within the cabinet.

For information on recommended:

Temperature: Section E.4, What is the recommended temperature set point and allowable fluctuation for general collections? and Section E.5 What is the recommended temperature for sensitive materials?

Relative humidity: Section F.6. What is the recommended RH set point and allowable range for general collections? and Section F.8. What is the recommended RH range for sensitive materials?

Light: I.4. What are radiation standards?

Particulate and gaseous air pollution, Sections K and I.

4. What is the equilibration relationship?

Objects continuously react/respond to their surrounding environment, absorbing and releasing heat and moisture (for hygroscopic materials) to reach equilibrium. Different materials "equilibrate" to the surrounding environment at varying speeds and rates, that is, they respond differently to changes in temperature and RH.

The equilibration relationship causes objects to react to changes in the environment, potentially damaging them, especially in situations where the change is extreme and prolonged and the material is constrained. Reactions to temperature and RH changes include swelling, contracting and cracking. Deterioration can go unnoticed for a long time (cracking paint layers) or can occur suddenly under extreme conditions (cracking of wood).

5. How do well- sealed cabinets protect collections?

Well designed and constructed sealed steel cabinets and exhibit cases buffer objects from climate extremes and fluctuations. Each successive layer within a multi-layered storage or exhibit space works to stabilize or reduce the range of fluctuations. These layers can also minimize energy loads that make for increased energy efficiency and sustainability. See Figure 4.1 and Chapter 7: Museum Collections Storage, Section A, What is a multi-layered collection storage system and how does it protect my collection? for detailed information.

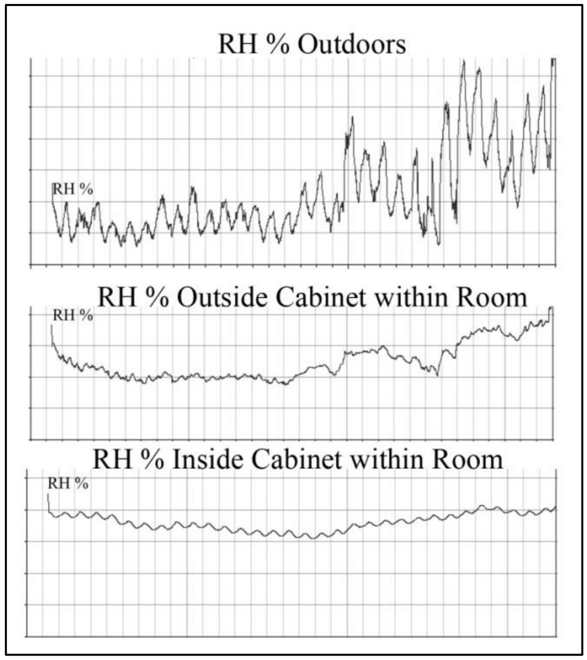

Figure 4.1 RH Readings Taken Outdoors, Within a Storage Space, and Inside a Steel Cabinet within the Storage Space without an HVAC over One Month

See Chapter 7 and Appendix T, for additional information on providing optimal storage conditions for collections.

C. Building Basics for Collections

1. What types of structures house collections?

The range of structures that house NPS collections fall into the general categories listed below:

- **Purpose built:** Structures specifically designed to house or display collections. They are well insulated and sealed against the exterior environment. Typically the storage or exhibit area(s) are separated from the exterior walls with corridors, offices, sales or similar spaces. Purpose built structures are designed to maintain a narrow temperature and relative humidity range, namely, a selected set point with the permissible fluctuation range. They exclude daylight and UV and IR radiation. These structures can support mechanical air handling systems that heat, cool, humidify, and dehumidify the air. See Section E.4, What is the optimal temperature set point and allowable fluctuation range for general collections? and F.6, What is the optimal RH set point and the allowable fluctuation range?

- **Adapted:** Structures originally built for purposes other than housing museum collections that are adapted (modified) to meet collections storage environmental, preservation, and protection needs. They range from recently constructed to older buildings.

They can be adapted for collections without concern for historic preservation as they are not classified as historic structures. These buildings can be adapted to maintain a selected set point with a relatively narrow temperature and RH fluctuation range. They can be readily adapted to block daylight, UV and IR without damage to the building fabric.

- **Historic structures:** Structures that are on or are eligible for the National Register of Historic Places and that exhibit and/or house collections. Because historic structures were designed for earlier building and/or human comfort standards, they should not be expected to maintain nor may they tolerate the same indoor environmental range as purpose built or adapted structures. Their envelope materials and assemblies may be incompatible with the desired indoor conditions for collections. They may have heating and cooling systems such as vents or fans that are incompatible with the installation of a HVAC system. Traditional methods such as opening and closing windows to regulate temperature spaces are not appropriate for spaces that house collections.

For all building types, avoid placing collections in spaces directly enclosed with exterior walls of existing masonry construction. Masonry absorbs rain water and releases that moisture (inwardly and outwardly) during the next sunny (or warm) day which adds to the humidity load of the interior space.

See *Museum Handbook* Part III, Chapter 8: Using Museum Collections in Historic Furnished Structures and the *COG* 4/7: "Museum Collection Storage Space: Is an Insulated Modular Structure Right for Your Collections?" for additional information.

2. How does the building type and envelope affect the collections environment?

The building envelope separates the collection from exterior temperature and RH fluctuations, light and pollutants. The roof, walls, floors, cellars, and other parts of the structure in contact with the exterior environment act as a buffer between the elements and the collection. Doors, windows, and chimneys can permit penetration that affects RH and temperature. They also permit light, and pollutant entry. Cracks, gaps, and the porosity of materials can hinder the effectiveness of the envelope. Similarly, dirt floors in cellars, unfinished basements and uninsulated attics negatively impact the internal environment. The type of building, its design and construction, and materials from which it is built from, such as wood, metal, concrete or masonry directly impact the interior environment.

All structures housing collections should provide a protective environment. Consult with your park facilities manager, and regional curator to determine what environment your structure is capable of maintaining.

In purpose built structures, exclude exterior windows in areas that house collections on exhibit or in storage, and treat doors, attics and basements to limit moisture and outside air penetration. In historic furnished structures, block chimneys, fill cracks and gaps, install UV filtering material over windows. Add shutters, blinds, and/or curtains to all windows. If appropriate, add double glaze windows, U-value (with thermal resistance and insulating properties) windows, or interior storm windows, or other appropriate material with UV filtering capability.

Design purpose built and adapted buildings to provide a highly protective building envelope. Historic structures may need to be adapted in order to protect the collection on exhibit from temperature and RH fluctuations and light penetration, including ultraviolet radiation. Consult with a historic architect to make sure that any modifications do not jeopardize the historic structure itself.

For collections that are stored in historic structures, in addition to adapting the structure as noted above, house the collections in sealed cabinets or within an insulated modular structure within the historic structure to moderate the negative impact of environmental fluctuations. If this is not possible, store the collections in another, more appropriate location.

3. *What features impact the environmental performance of a historic structure?*

Most historic structures were not designed to rely on modern mechanical systems such as heating, ventilation, and air conditioning (HVAC) systems for controlling climate. They include many features that non-mechanically stabilize their interior environments, such as high mass exterior walls and shutters on windows. The design, materials, type of construction, size, shape, site orientation, surrounding landscape, and climate all play a role in how buildings perform. Historic building construction methods and materials often maximized natural sources of heat, light and ventilation to respond to local climatic conditions.

The key to controlling the environment in a historic structure is to identify and understand the building's existing environmental controls and how they function. It is essential to understand and use the historic building's inherent sustainable qualities as originally intended to ensure that they function effectively together with any new treatments, to help create the desired environment. See *Preservation Brief 3*, "Improving Energy Efficiency in Historic Buildings" and *Preservation Brief 24*, "Heating, Ventilating, and Cooling Historic Buildings – Problems and Recommended Approaches" for additional information.

It is important to balance the needs of the collections with those of the historic structure itself. Human comfort factors should also be taken into account. If these present an issue, take appropriate action to protect the collection, or consider relocating the collections.

4. *How do structures respond to the local*

Temperature extremes and changes will affect the building envelope and in turn, interior spaces. Temperature and RH disparity between *climate?*

the exterior and interior can result in condensation on windows, around window and door frames, and within walls as cooler interior air meets the warmer outside air (or vice versa). Condensation can lead to mold, rotting of wood, flaking paint, spalling of exterior walls, and leaks. See F.2 for information on dew point.

Monitor temperature and RH outside and inside the structure for a minimum of one year to learn how the building envelope responds to the local climate and seasonal variations. Thereafter, do continuous monitoring in order to effectively ensure and maintain a stable collections environment. Evaluate the data to understand how the structure responds to seasonal changes. Based on the climate data and information on the condition of the collection, determine what and how much additional protection the collections need.

Be aware that most spaces are warmer near their ceilings resulting in lower RH at the upper levels and higher RH at lower levels. When necessary, consider relocating sensors or taking measures to mitigate thermal stratification. However, be aware that fans will cause a disruption of the motion detector security system.

Many historic structures were designed for human comfort in a specific local environment. They may have structural elements (such as ventilation shafts) to help accomplish this. These architectural features may be able to be adapted to help regulate the interior environment of a structure based on exterior conditions.

5. *When should I have a Historic Structure Report done?*

To understand how the historic structure functions and impacts collections, arrange for a Historic Structure Report *before* moving collections into the structure, or arrange for an update of the report. Monitor and evaluate the interior climate for at least one year to obtain baseline information and to see how the different seasons and local climate affect the structure.

Use this information to determine how the structure performs and to address climate issues within the structure and the area housing the collections. Continue ongoing monitoring. See *Preservation Brief 43* "The Preparation and Use of Historic Structure Reports" for more information.

6. *Are mechanical systems appropriate for historic structures?*

Consult with a historic architect and mechanical engineer with knowledge and experience with historic structures to determine whether a mechanical system is appropriate for the historic structure. **Note:** Introducing humidity and temperature controls into buildings that were not designed for HVAC systems can create serious problems for the structure. Where possible, use non-mechanical methods to maintain a stable climate in historic structures.

First do a thorough assessment of the structure, considering all potential and unintended consequences of possible HVAC installation and consider other alternatives in consultation with a historic architect.

Be aware that humidistatically controlled systems that introduce humidity into the air can be effective in improving the environment in historic structures. However, the added humidity may be destructive to the building fabric. See Section H 6. "What are humidstatically controlled heating and ventilation systems?"

If mechanical systems are installed in historic structures they have to be continuously monitored to prevent any malfunction that can damage collections and the structure itself. See *Preservation Brief* 24, "Heating, Ventilating, and Cooling Historic Buildings: Problems and Recommended Approaches" for more information.

7. How do I improve and stabilize the collections environment in different types of structures?

First assess the structure's interior environment. Then obtain and analyze baseline temperature, RH, light and air pollution data for at least a year and through different seasons in order to understand how the space and structure performs. Consider what elements of the building envelope block or mitigate the environmental agents of deterioration and which may introduce them to the collections environment. For example, thick masonry walls will buffer against fluctuations in temperature, but an unblocked window allows in sunlight as well as heat or cold penetration, and cause temperature swings and may lead to condensation.

When a structure is to be adapted to house collections, consult with a building engineer, historic architect, and park facilities staff on how it can be adapted to provide a stable environment for collections. This includes non-mechanical means of controls, such as managing the building envelope, using an insulated modular structure within the historic structure, to mechanical controls, such as installing a HVAC system.

When making adjustments to the environment within a historic structure, ***always*** begin with measures that require the least change to the building. This may include using storm windows with UV filtering capability, shutters, blinds, and curtains.

Only *consider adding insulation materials and an HVAC system as a last resort, and* only *if it is determined that the materials and the HVAC system will not cause harm to the historic fabric of the building.*

See *The Secretary of the Interior's Standards for Rehabilitation & Illustrated Guidelines on Sustainability for Rehabilitating Historic Buildings* for more information. Refer to Sections I, K and M on how to moderate fluctuations in temperature and RH, and how to block UV and minimize IR, visible light and air pollution.

Despite improvements to the structure, certain objects in the collection still may not be able to withstand the ambient environment. House these objects in containers or enclosures designed to fit their specific environmental needs or move to a facility capable of maintaining the required controls.

8. Does building occupancy and related activities affect the collections environment?

People, daily activities, electronic and office equipment, lighting and furnishings affect the collections environment. People emit heat and moisture that affect the temperature and RH levels within a space. They also introduce particulate air pollutants, such as dust, into a space. The larger the number of people and/or activities, the more dramatic the impact on the climate and the increased potential for damaging environmental fluctuations.

Mediate these fluctuations by ensuring adequate ventilation and climate control. Limit the number of people in an area at one time and set a limit on the number of visitors per day. Increase the distance between the visitors and the objects on open display to reduce the dust levels. Work with park interpretation and facilities management to manage tours of furnished historic structures. Have researchers work outside of the collections area and bring study collections to them. Use LED (light-emitting diode) lights that do not emit UV and emit minimal heat. Power down lighting and electronics when not in use.

Construction and renovation work pose a great threat to the structure and collections. Monitor the work area and equipment. Light, pollutants, chemicals, vibrations, and the presence of extra people will affect the environment and building structure. Make sure all equipment is turned off when not in use to prevent heat build-up and fire. Seal off the work area from the rest of the collection. Move or monitor objects especially sensitive to vibration, temperature, or moisture fluctuations while the work takes place.

9. Who should be involved in improving the collections environment within a structure?

Before embarking on a project to improve the collections environment, consult and collaborate with your regional curator, conservator, park facilities manager, structural engineer and an architect experienced in working with museum collections. For historic structures work with an architectural conservator and a historic architect.

Make sure that the contract includes a schedule for museum staff or the construction manager to inspect the construction site on a regular basis to ensure that all necessary precautions are taken.

D. Types of Deterioration

1. What is deterioration?

Deterioration is any chemical or physical change in the condition of an object. Physical and chemical deterioration often occur simultaneously. Deterioration is an inevitable, natural process by which an object reaches a state of chemical and physical equilibrium with its immediate environment.

Exposure to agents of deterioration, including light, incorrect levels of temperature and RH and pollution accelerate the rate of deterioration.

Become familiar with the inherent weaknesses and likely types of deterioration of the materials and objects in your collection so that you can readily monitor them for changes in condition. When you observe signs of damage, identify the type of damage (i.e. chemical, physical, and mechanical), and determine the cause for the changes and take appropriate action.

2. *What is chemical deterioration?*

Chemical deterioration is any change in an object that involves an alteration of its chemical composition. It is a change at the atomic and molecular level. Chemical change usually occurs because of reaction with another chemical substance (e.g., water, pollution, pest waste) or radiation (i.e., light and heat). Examples of chemical change include:

- oxidation of metal (rusting)
- dissolution of stone
- staining of paper documents by adjacent acidic materials
- foxing on paper prints and drawings
- fading of dyes and pigments
- darkening of resins
- darkening and embrittlement of pulp papers
- embrittlement of textile fibers
- bleaching of many organic materials
- cross-linking (development of additional chemical bonds)
- acid hydrolysis of cellulose nitrate film

3. *What is physical deterioration?*

Physical deterioration is a change in the physical structure of an object that does not involve a change in the chemical composition. It is often caused by improper levels of, or rapid and extreme fluctuations of temperature and RH or the interaction with some mechanical force. Examples include:

- melting or softening of plastics, waxes, and resins caused by high temperature
- cracking or buckling of wood caused by fluctuations in relative humidity
- warping of organic materials caused by high or low relative humidity
- shattering, cracking, or chipping caused by impact

- crushing or distortion caused by a harder material pressing against flexible material

- abrasion caused by a harder material rubbing against a softer material

- structural failure such as metal fatigue,tears in paper, rips in textiles

- stress caused between different materials on a composite object

Physical and chemical deterioration are interrelated and often occur simultaneously. For example, chemical changes in textiles caused by interaction with light also weaken the fabric so that physical damage such as rips and tears are likely to occur.

4. What is biological deterioration?

Biological deterioration results from several factors including excessive moisture, temperature, or food supply for museum pests. A malfunctioning HVAC system or exposure to moisture from exterior walls and/or windows can create an environment surrounding an object conducive to biological deterioration, in particular, mold.

With the right conditions, mold will grow quickly and damage can be irreversible. These conditions are very likely to support a variety of museum pests. Organic objects such as textiles, paper, wood, leather, horn and hair are particularly susceptible.

Examples of biological damage include:

- staining and weakening of wood, paper, textiles, leathers, and skins and other organic materials through mold growth

- loss of sizing in paper materials, making them more hygroscopic

- etching of inorganics by fungal acids

- rotting of wood by growing fungus when the RH is high

- staining or losses from the activity of rodents, birds, or insect pests

See *COG* 3/4: "Mold: Prevention of Growth in Museum Collections" for more information.

5. What is inherent vice?

Inherent vice is the propensity of certain materials to deteriorate because of their internal characteristics, incompatibility of materials, poor quality, unstable materials, or processing. This mechanism of deterioration is often called *inherent vice* or *inherent fault*.

In nature, organic materials often possess characteristics that protect them from natural degradation when the organism is alive but which quickly break down with the death of the organism. Their structure and composition may include features such as protective layers, insect and mold resistant chemicals, and photochemical protection.

Processing during object manufacture can remove these natural safeguards. Additives may be applied to produce a desired result without concern for long-term preservation (such as the addition of metal oxides in the manufacture of weighted silk or the use of formalin on fish and reptiles to fix the specimen). This processing causes inherently less stable materials or combinations of mutually incompatible substances that result in damaging interaction. Some inorganic materials may also be inherently unstable, for example pyrites that contain microcrystalline iron sulfides.

There are three kinds of inherent vice:

- **Short-lived materials**. Short-lived materials are the result of manufacturing processes or those materials that were not intended for long term use. Examples of impermanent materials with inherent vice include:

– cellulose nitrate and cellulose acetate film

– wood pulp paper

– certain plastics

– magnetic or digital media

- **Structural nature**. Inherent vice can also be related to the structure of an object. Poor design, construction or application of materials may cause structural failure. Examples of such damage include:

– marble table top causing bucking of supporting legs

– unraveling basketry coils

– cabinet door edges shearing away at the closure edge

- **History**. The way an object was made, processed, used, or housed before entering the collection may lead to inherent vice. Here damage and deterioration is caused by the original function and manufacture of the object, its maintenance or environment. Examples include:

– accumulation of dissimilar paint layers, such as oil and latex

– saturation in food storage containers

– deposits of soluble salts in archeological ceramics during burial

– non stainless steel wire in bird and mammal study skins or taxidermy mounts which may rust

Become familiar with the history of objects in your collection, including the processing of materials, manufacturing details, and previous use. Examine similar objects and learn to recognize inherent vice in your collections.

6. *How do I identify active deterioration and its causes?*

Active deterioration shows a continuing deleterious change or growth on an object over time. Active corrosion or condensation can be an early indicator of a humid environment and can help you determine what issues need to be corrected. Seek visual clues to determine what could be affecting the object and causing damage, such as improper environmental levels, RH or temperature fluctuation, light exposure, or chemical deterioration of surrounding objects or storage materials.

These include:

Cause	**Visual Clue/Damage**
Incorrect temperature and RH	Condensation forming on cold surfaces
High RH	Corrosion of metals; mold growth on paper, books, or walls, condensation forming on cold surfaces, presence of insects such as silverfish that thrive only in humid environments
Low RH, high temperature	Cracking or distortion of organic objects, phase changes in some minerals
Leaks, high RH	Water stains on ceilings or walls
Exposure to light	Color shift and/or embrittlement in organic materials, basketry, biological specimens, feathers, furs, fossils with organic coatings and consolidants, leather, painted surfaces, paper, parchment, works on paper, textiles, some minerals, wall paper, wood and plastics

Figure 4.2. Active Deterioration Cause and Visual Clue/Damage Chart

E. Temperature

1. What is temperature?

Temperature is a measure of the motion of molecules in a material. Molecules are the basic building blocks of everything. When the temperature increases, molecules in an object move faster and spread out; most materials then expand. When the temperature decreases, molecules slow down and come closer together; materials then contract.

Temperature and temperature variations can directly affect the preservation of collections. Temperature is also a primary factor in determining RH levels. When all other variables are held fixed, an increase in temperature generally results in a decrease of relative humidity.

2. How does temperature affect objects?

Temperature affects objects in a variety of ways. As temperature changes, objects will reach thermal equilibrium and adjust to the temperature of their surroundings. Increased temperatures generally cause expansion and decreased temperatures usually cause contraction. The amount of surface area exposed and the density of the material impact the time the object will take to reach equilibrium. Inappropriate temperature can accelerate chemical, physical, and biological processes that cause deterioration.

At higher temperatures:

- *Chemical reactions increase*. This is especially problematic for materials such as acidic paper, plastics, digital media and photographic materials. For example, high temperature leads to the increased deterioration of cellulose nitrate film. If this deterioration is not detected, it can lead to a fire. Most chemical reactions double in rate with each increase of 18°F (10°C). High temperatures can also cause evaporation of moisture from objects and that can in turn, result in deformation or cracking.

- *Biological activity increases at warmer temperatures*. Insects eat more and breed faster, and mold grows faster within certain temperature ranges.

- *Materials can soften*. Wax may sag or collect dust more easily on soft surfaces, adhesives can fail, lacquers and magnetic tape may become sticky.

At lower temperatures:

Very cold temperatures can make certain materials more brittle and prone to cracking, flaking, and other damage. Materials such as varnishes, lacquers, wood, oil, alkyd, and acrylic paints are especially at risk and need to be handled with extreme care. See *COG* 3/6: “An Insect Pest Control Procedure: The Freezing Process” for information on which materials not to freeze.

In general, the rate of any chemical reaction increases with rise in temperature, so in many instances, judiciously lowering temperature can improve preservation.

3. *What deterioration is caused by fluctuations in temperature?*

Temperature fluctuations can cause materials to expand and contract rapidly, setting up destructive stresses on the object. Fluctuations that occur faster than an object's ability to adjust to the change are most likely to cause damage such as cracking or exfoliating. Soluble salts in archeological and paleontological material may undergo cycles of efflorescence and deliquescence, resulting in surface delamination or other physical damage. Rapid variations can cause more problems than the specific level.

Avoid abrupt and extreme changes in temperature. It is often rapid fluctuations that cause more problems to an object than the specific level. This is particularly true for composite objects. If objects are housed outside such as a gun carriage, repeated freezing and thawing can cause damage. Temperature is also a primary factor in determining relative humidity. When temperature varies, RH may vary as a consequence.

4. *What is the recommended temperature for general collections?*

NPS collections are located in a wide range of climates throughout the U.S. Therefore you should determine the temperature set point based on an evaluation of your collection needs, the type of structure in which the collections are housed, the local climate and seasonal variations.

In exhibit, storage and research spaces, where comfort of people is a factor, the recommended temperature range for most NPS collections lies between 59 – 77°F[i] (15 – 25°C). Keep the temperature as level as possible.

Figure 4.3. Recommended Temperature Set Point for General Collections

In areas where comfort of people is not a concern, temperature can be kept at much lower levels, but above freezing**.** Studies indicate that reducing the temperature can extend the life of many materials. Certain materials require even lower temperatures, including cold storage. See Section E.5 for information on temperature standards for photographic materials and Appendix T, Section V, Biological Low-Temperature Collections. **Note: The cooler the better.** However, irrespective of where your collections are located, maintain a controlled temperature and avoid abrupt changes in temperature for long term collection preservation.

Over the year you may want to allow the set point to vary or drift with the seasons**.** Drift means that your set point varies in different seasons; usually higher temperature in the summer and lower in the winter. Allowing drift will often reduce energy costs over the long-term as mechanical systems work less to maintain the appropriate environment. **These variations should be gradual, taking place over weeks and months.** See F.7 for information on seasonal drift.

Wherever your collections are located, keep the temperature within the permissible range and avoid abrupt fluctuations to promote long term collections preservation.

House sensitive or chemically unstable materials separately within the general storage area or in a separate facility at the appropriate temperature. Chemically unstable materials with inherent vice such as acidic paper, modern electronic and digital records, certain photographic materials, and certain plastics require cold storage to slow the chemical processes responsible for their deterioration. Note that items in cold storage must be properly packaged so that when removed from storage, they can equilibrate to ambient conditions without condensation on the surface of the objects.

5. *What are the temperature standards for photographic materials?*

Museum standards for photographic media recommend or require cold temperatures to preserve film and color media. The Code of Federal Regulations, *Facility Standards for Records Storage* (36 CFR 1228.232 (b.) Subpart K, Sept 2005) that applies to federal archives and museums **requires** cold storage for film and color photographic materials at 35°F or below and 35% RH. The criteria set by the International Standards Organization (ISO) 18911, *Safety Film Storage* **recommends** cold storage at 35F or below at 30 - 40% RH (or cool storage at lower RH) for the extended storage of the above-mentioned materials. Under Directive 1571 - Appendix A the U.S. National Archives and Records Administration lists cold storage as a standard.

See COG 14/10 *Cold Storage for Photograph Collections –An Overview* and Appendix T: Section V, Biological Low-Temperature Collections for additional information.

F. Relative Humidity

1. *What is relative humidity (RH)?*

Relative humidity (RH) is a ratio (expressed in percent) between the mass of water vapor in a fixed volume of air (the absolute humidity) and the maximum mass of water vapor that a fixed volume of air could hold (without condensation) at the same temperature. RH varies with changes in temperature and moisture content of the air. The relative humidity goes up as the air approaches saturation (100%) for a particular temperature. The general relationship between temperature and humidity is that for a given volume of air, as the temperature rises, the humidity decreases and *vice versa*.

If temperature is lowered without some means of reducing the moisture content in the air, then the RH will rise. Conversely, if the temperature is raised without some means to add moisture to the air, the RH will decrease. For example, if you have a mold problem it is not enough to just lower the temperature; the RH must be controlled as well.

Relative humidity is important because of the role water plays in various chemical and physical forms of deterioration. There are many sources for moisture and/or water; exterior (outdoor) humidity levels, rain, nearby bodies of water, wet ground, broken gutters, leaking pipes, damp basements, moisture in the walls, human respiration and perspiration, wet mopping, flooding, and cycles of condensation and evaporation.

All organic materials and some inorganic materials absorb and give off water depending on the RH of the surrounding air. Effects of RH on objects include:

- faster corrosion of metal objects at higher RH
- pests and mold growth are more common at higher RH
- shrinking and cracking in organic materials can occur at low RH

The following definitions clarify how these factors affect the environment in your museum.

Absolute humidity (AH) is the quantity of moisture present in a given volume of air. It is not temperature dependent. It can be expressed as grams of water per cubic meter of air (g/m3). A cubic meter of air in a storage case might hold 10 g of water. The AH would be 10 g/m3.

Dew point (or saturation temperature) is the temperature at which the water vapor begins to condense out of the air. It is a direct measure of the mass fraction of water vapor in the air. If the temperature drops below the dew point the water will condense forming dew. In a building, the water vapor may condense on colder surfaces in a room, for example, walls or window panes.

Relative humidity relates the moisture content of the air you are measuring (AH) to the amount of water vapor the air could hold at saturation at a certain temperature. Relative humidity is expressed as a percentage at a certain temperature. This can be expressed as the equation:

$$RH = \frac{\text{Absolute Humidity of Sampled Air x 100}}{\text{Absolute Humidity of Saturated Air at Same Temperature}}$$

In many buildings it is common to turn the temperature down in the evenings when people are not present as a sustainability measure. If you do this you may cause unacceptable daily swings in the RH. Turning down the heat to increase the RH may be beneficial to the collections if the RH is too low. However, turning down the heat in relatively damp conditions may increase the RH to the level where mold grows.

2. Why is dew point an important element of managing the museum environment?

Dew point is an important consideration in managing and maintaining a stable environment as it relates to RH. At a constant dew point, when temperature increases, RH decreases; when temperature decreases, RH increases. Raising or lowering temperature without accounting for dew point can lead to incorrect RH levels and create a risk of condensation. Humidifying the air raises the dew point and dehumidifying the air will lower it.[ii] Making such changes should always take structural constraints into account. If a structure is heated and humidified in the winter or air conditioned in the summer, the dew point created by the mechanical system can cause condensation to form in the walls. This is especially problematic in historic structures.

3. What is the relationship between temperature and relative humidity?

Relative humidity is related to temperature. In a closed volume of air (such as a cabinet, exhibit case or storage area) where the amount of moisture is constant, a rise in temperature results in a decrease in RH and a drop in temperature results in an increase in RH. For example, turning up the heat when you come into work in the morning will decrease the RH; turning it down at night will increase the RH.

In a closed system, relative humidity is **inversely** ***related to temperature (i.e., when the temperature goes up, the RH goes down; when temperature goes down, the RH goes up.)***

Changing any one of these variables will impact the others, resulting in a change in the environment. The environment will seek equilibrium (a natural balance) when there is a change in temperature, RH, or dew point. Understanding this relationship allows you to manage your collections environment more effectively.

4. How do materials react to changes in relative humidity?

Most **organic materials** are hygroscopic. Hygroscopic materials absorb and release moisture to the air. The RH of the surrounding air determines the amount of water in organic materials. When RH increases they absorb more water; when it decreases they release moisture to reach equilibrium with the surrounding environment. Moisture equilibrium is relatively slow and can take days or weeks to complete. The amount of moisture in a material at a certain RH is called the *Equilibrium Moisture Content* (EMC). Over time, these reactions with water can cause deterioration. Refer to Appendix N: Curatorial Care of Wooden Objects for more information.

Most **inorganic materials** are not hygroscopic. They do not equilibrate with changes in RH as they do not naturally contain moisture. However, too much moisture in the air will cause mold growth, corrosion, and other damage to metals. Certain minerals such as salts will absorb moisture from the air, as will other inorganic materials.

5. What deterioration is caused by incorrect relative humidity?

Deterioration can occur when RH is too high, too low or fluctuating.

- **Too high:** When relative humidity is high, chemical reactions may increase, just as when temperature is elevated. Many chemical reactions require water; if there is a lot available, then chemical deterioration can proceed more quickly, such as metal corrosion, oxidation of iron sulfides, and hydration of minerals. High RH levels cause swelling and warping of wood and ivory. High RH can make adhesives or sizing softer or sticky. Paper may cockle, or buckle; stretched canvas paintings may become too slack. High humidity also supports biological activity. Mold growth is more likely as RH rises above 65%. Insect activity may increase. RH levels above 20% promote highly destructive oxidation in specimens containing microcrystalline iron sulfides

- **Too low:** very low RH levels cause physical damage including shrinkage, warping, and cracking of wood, ivory, teeth, bone and shell; shrinkage, stiffening, cracking, and flaking of photographic emulsions and leather; desiccation of paper, adhesives, and basketry fibers.

- **Fluctuating:** changes in the surrounding RH can affect the water content of objects, which can result in dimensional changes in hygroscopic materials. They swell or contract, constantly adjusting to the environment until the rate or magnitude of change is too great and deterioration occurs. Deterioration may occur in imperceptible increments, and therefore go unnoticed for a long time (such as cracked paint layers). The damage may also occur suddenly (for example, cracking of wood). Materials particularly at high risk due to fluctuations are laminates, constrained and/or composite materials such as photographs, magnetic media, veneered furniture, paintings, and other similar objects. Greater surface areas also put materials at a higher risk.

Become familiar with objects in your collection and how they may react to RH changes.

6. What is the recommended RH set point and fluctuation range for general collections?

NPS collections are made of a wide variety of materials that are located in many different climate zones, and that are housed in a range of structures throughout the U.S. Therefore, you should determine the set point for your collections by evaluating the nature of the materials in the collection, the space in which they are housed, and your local climate. Do this in consultation with your regional curator, a conservator or other expert in museum environments.

***The relative humidity set point for most NPS collections lies between 45 – 55 %. Ideally, fluctuations should not exceed ± 5% from the set point*.**

Figure 4.4. Recommended RH Set Point and Fluctuation Range for General Collections.

If you are in climate zone with distinct seasons, you may allow for a seasonal drift in your RH set point, yielding a total annual range of 40% minimum to 60% maximum. The fluctuations should not exceed ± 5% for each seasonal set point. Monitor environmental conditions and review the data monthly. See E.7 for information on seasonal drift. However, if you are located in an extreme climate, such as the arid Southwest, 35% RH [iii] could be the set point as objects will have equilibrated at much lower RH levels.

For example, if you are in Ohio you may determine that the set point is 50% with an allowable range of ±5%. The humidity could go as high as 55% or as low as 45% within a month.

Do not allow the RH to go as high as 65% as mold might develop. Below 35%, certain material (teeth, bone, and shell) may become brittle, crack, and spall. See Figure 4.5 for the recommended RH levels for sensitive materials.

Wherever your collections are located, keep RH within the permissible range and avoid abrupt fluctuations to promote long term collections preservation.

Consult your regional curator or a conservator to determine your set point. Monitor environmental conditions and evaluate the data regularly. Also monitor the condition of the objects. If climate induced damage is observed, implement improvements. The greater and more prolonged the RH fluctuation outside the allowable range, the greater the risk to collections. There are many ways to limit fluctuations, not all dependent on having an expensive mechanical system. For example, good climate control is achievable by housing collections in well-constructed and sealed storage and exhibit cases within a well maintained building envelope. These will buffer the interior contents from RH fluctuations. Good enclosures also help protect collections during shut-downs or failures of mechanical systems as well as protecting against other agents of deterioration. See Figure 4.1.

For collections housed in historic structures, work with facilities management to achieve and maintain an optimal set point and a permissable range. House sensitive materials with different requirements separately from the general collections. See Figure 4.5 for the recommended RH levels for sensitive materials.

If you are planning to build a purpose-built storage facility or exhibit gallery to house sensitive collections, for more specific design parameters, refer to the American Society of Heating, Refrigeration and Air-Conditioning Engineers [ASHRAE] *Handbook*-HVAC Applications, Chapter 23, Museums, Galleries, Archives and Libraries (www.ashrae.orga) and the PAS198:2012 Specifications for managing environmental conditions for cultural collections published by the British Standards Institution.

7. What is seasonal drift?

Over the year you may want to allow the set point to vary or drift with the seasons**.** Drift means that your set point varies in different seasons; usually higher RH in the summer and lower RH in the winter. Allowing drift will often reduce energy costs over the long-term as mechanical systems work less to maintain the appropriate environment. These variations should be gradual, taking place over weeks and months and should not exceed the recommended fluctuation limits. They should not be brief and variable. For collections housed in a historic structure, allowing for seasonal drift is likely to contribute to the preservation of the structure itself.

8. What is the recommended RH range for sensitive materials?

House sensitive materials separately from the general collections, such as in another storage space or cabinet. For sensitive materials, see the Figure 4.5 below.

Material Type	**Relative Humidity**
Unstable or corroding metal Stable metal	<15% <35%
Teeth, bone and shell	30 – 55% (lower than 30% can result in mechanical damage)
Naturally mummified animal remains	15 – 20%
Stable pyrite and pyritic specimens Unstable pyritic specimens	<45% <20%
Freeze dried specimens	<40%
Plastics	30 – 45% (See *COG* 8/4 for additional recommendations)
Most photographic materials	30 – 40% (if housing photographic materials within a general area. See E.5 for photographic storage standards.)

Figure 4.5. Optimum RH Ranges for Sensitive Materials

Materials recovered from archeological sites may need to be housed within special RH ranges. The condition of these objects depends on their equilibration to the conditions in the surrounding soil. Once excavated, these materials have to adjust to a new and different environment. See Appendix I: Curatorial Care of Archeological Objects for more information. For objects on exhibit, see *MH-III,* Chapter 7, Section I, Preserving and Protecting Objects in the Exhibit Process.

G. Monitoring and Analyzing Temperature and Relative Humidity

1. Why should I monitor and evaluate temperature and relative humidity?

Ongoing monitoring and evaluation of temperature and RH enables you to understand the environment in your storage and exhibit spaces over time. It allows you to:

- establish a baseline of temperature and RH to see if the spaces housing collections are providing an optimal environment
- identify temperature and RH variations in areas housing collections
- monitor equipment to be sure it is working properly, including making sure that data loggers are properly calibrated
- establish how the internal climate performs in relation to the local climate through different seasons over time
- determine and then take the appropriate action to lower the risk of damage to collections when recommended temperature and RH levels are exceeded
- develop and implement a climate control strategy to improve the overall environment, including implementing non-mechanical and "low tech" solutions where possible determine whether your strategy is working

2. What kind of monitoring equipment should I use?

Most dataloggers provide information on temperature and/or RH in real time as they occur. They are small and can easily be placed in storage areas, cabinets, exhibit cases, furnished historic structures, shipping crates, and other area where collections are located.

Other equipment used to measure and/or record temperature and RH, includes hygrothermographs, hygrometers, psychrometers and humidity indicator strips. However, dataloggers make for convenient and efficient recording and analysis of temperature and RH. See *COG* 3/3: "Comparing Temperature and Relative Humidity Dataloggers for Museum Monitoring (Revised)" for more information.

3. Where should I place dataloggers to monitor the environment?

Use dataloggers to set up a monitoring program to better understand your collections environment. Place dataloggers in different locations, such as the basement, and first and second floors of a furnished historic structure. This will allow you to gather data to evaluate conditions in the spaces housing collections. Also place dataloggers inside selected storage cabinets and exhibit cases to monitor how well these enclosures maintain a stable environment. Place the datalogger away from the windows, vents, air intake units and other sources of heat, cold and light to prevent incorrect readings. Keep in mind the thermal gradient within a room and place dataloggers at different heights. Also place dataloggers in areas or containers that provide microclimates for sensitive materials. Make sure dataloggers are calibrated.

Install dataloggers into spaces before introducing collections to better understand the environment. Monitor for at least a year before moving collections into the space, and then do ongoing monitoring. If possible, install a datalogger outside to monitor temperature and RH outside the structure or obtain readings from the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center web site for climate data.

4. What data should I collect to manage the collections environment?

Collect information from daily, weekly, monthly and annual readings and keep a parallel record of observations, noting seasonal variations, abnormal occurrences, such as exterior climatic conditions, a leaky roof, re-calibration of equipment, or an unusual visitation pattern. Use this information to evaluate your local climate, identify short-term and long-term impacts on the collections environment and compare data across seasons and visualization of long-term trends.

Retain the information collected, such as datalogger graphs in order to assess building and HVAC performance over time. Review and evaluate data regularly. When evaluating data, consider the following variables and how they affect the collections environment:

- quality, condition and components (such as a vapor barrier, insulating value of windows) of the building envelope housing the collection
- staff activity
- public visitation
- local climate
- events such as leaks that affect RH and temperature
- HVAC equipment performance or failure
- condition and accuracy of the monitoring equipment

Then determine:

- if temperature and RH levels are stable and within the recommended set point and permissible range
- which spaces have the most stable levels, and why and how those conditions can be replicated to obtain stable levels in other spaces housing collections

Monitoring and evaluating data allows you to:

- make informed decisions on how to control temperature and RH
- identify and respond to problems in your collections environment
- group and house collections based on most suitable available environmental conditions
- evaluate whether changes you have made are improving the environment
- assess future priorities
- build an argument about the need to get environmental upgrades or a new building

H. Methods of Controlling Temperature and Relative Humidity

1. *What steps should I take to control and maintain a stable climate?*

Follow the steps outlined below to control and manage temperature and RH in order to provide a stable environment for your collections.

- **Gather information**

An effective climate control strategy is based on reliable information gathered on an ongoing basis about your collections, spaces housing collections, the building envelope, interior environment, and the local climate. Collect data for a minimum of one year before establishing an optimal set point. Do ongoing monitoring and evaluation, and take appropriate actions to maintain optimal conditions.

- **Determine acceptable temperature and RH set points**

Determine your temperature and RH set points after evaluating the:

– nature and condition of the materials in the collection

– nature and condition of the structure housing the collection

– local climate and seasonal variations

– events that influence the interior climate such as leaks, HVAC malfunction, rain, wet mopping, or unusual or excessive visitation patterns

– ability of non-mechanical and mechanical systems and/or equipment to maintain the temperature and RH set points and allowable fluctuations

– ability of staff to maintain equipment

Be aware that the narrower the range (both temperature and RH), the greater the building environmental equipment, maintenance and operation cost.

- **Use a team approach to control and manage your museum climate**

Assemble a qualified team to carefully plan and implement a climate control strategy. Work with your regional curator, facilities management, a conservator and mechanical engineer with museum climate expertise. As needed, consult a historic architect on all aspects of the strategy, and its implementation and commissioning. The strategy should keep energy costs in mind.

- **Implement non-mechanical measures to control climate when and wherever feasible**

Non-mechanical methods described in this chapter will greatly contribute to stabilizing your collections climate. These controls do not require installing fixed mechanical systems and can aid in reducing energy costs. Take the structure and local climate into consideration when developing a non-mechanical and sustainable control plan. Monitor regularly to insure that these controls are effective and adjust accordingly.

- **Maintain the building envelope**

A well sealed and maintained building envelope excludes and/or minimizes the impact of climate events, and temperature and RH extremes. In consultation with maintenance, examine the structure and spaces housing collections to identify possible sources of moisture and air seepage, and work to correct these problems.

Sources of high RH levels include:

- leaking roof, ceiling, or windows
- gaps in walls, floors, or foundation vapor barrier
- dirt cellars
- seepage or cracks in and around windows and doors
- leaking plumbing
- damaged gutters and downspouts

- wet walls and foundations from poor drainage

- open water sources such as sinks or toilets

- vegetation that grows on or next to exterior walls

- **Moderate and/or control the interior environment by implementing non-mechanical or "low tech" solutions for objects on exhibit and in storage**

– Separate collections storage areas from work spaces and areas where people are likely to gather.

– Limit the number of visitors in spaces housing unenclosed objects such as in furnished historic structures. Large groups of people can raise the RH from moisture introduced by breathing and perspiring.

– Locate electronic equipment outside the collections area to prevent additional heat buildup.

– Exclude or block windows in storage areas to minimize temperature and RH fluctuations.

– Install double glazed windows, U-value windows (with thermal resistance and insulating properties) and interior storm windows (with UV blocking capability) to buffer against temperature and RH extremes and fluctuations while blocking UV. For historic structures, consult with a historic architect and the regional curator when considering this step.

– Exclude or block natural light in storage areas

– Block and/or filter natural light in exhibit galleries and furnished historic structures.

– Install blinds, curtains, drapes, and/or exterior shutters as appropriate to minimize heat buildup from sunlight. Use these coverings to block UV in historic structures.

– Use LED lighting where possible to avoid heat build up and exposure to UV.

- **Containerize objects**

– House objects in well sealed and constructed cabinets, cases, including exhibit cases, boxes, folders and enclosures to buffer temperature and RH flucturations, and limit light damage and help protect collections from pests.

- Develop separate storage zones to accommodate the different environmental needs of collections. Housing objects that require cooler or dryer conditions separately will enhance efficiency by maintaining a specific target climate range.

- Create microenvironments to house sensitive objects (such as some metals, textiles, paper, pyritic minerals, and fossil specimens) that require a specialized RH level.

- **Moderate areas adjacent to the building envelope**

Trees immediately adjacent can help moderate the interior environment by providing shade in the summer and permit the passage of sunlight in the winter. However, be aware that vegetation that is too close to a structure may habor museum pests and also elevate local moisture levels.

- **Do ongoing monitoring and evaluation**.

Continue on-going monitoring and data evaluation to determine how well your strategy is working after implementation, to identify trends and problems, and to take appropriate actions to maintain optimal conditions.

2. How do sealed cabinets help stabilize the collections environment?

Housing objects in well designed and constructed sealed steel cabinets and cases will buffer against temperature and RH extremes and fluctuations. They provide an effective, low cost and sustainable way to create a stable environment. In a temperate climate, a well-sealed cabinet interior can provide a stable RH between 45% and 55%. See Figure 4.1. Continue on-going monitoring to ensure that the target climate within cabinets is being maintained.

Certain climate sensitive materials such as metal require temperature and RH levels that the structure or space cannot readily maintain. House these objects in separate spaces or cabinets, or a specialized microclimate. This approach allows you to house sensitive materials at specific temperature and/or RH ranges that cannot be easily maintained within general collections areas and in historic structures. Examples include:

- freezer storage for cellulose nitrate film and other photographic materials

- sealed dry storage containers for metals and other materials that require low RH

- humidity-buffered and temperature controlled cases that house fragile organic and inorganic materials

temperature-controlled vaults for manuscript collections

- prefabricated insulated modular structure for storing collections in a historic or adapted structure

For more information, see *MH-I*, Chapter 7, Museum Collections Storage and Appendix T: Section D. 8, What storage systems will best protect my park's biological collections?

3. *What is humidity buffering?*

Many materials in a museum environment absorb water and give off water. These materials can slow RH changes and *buffer* the environment around the object to minimize damage. Certain organic materials (cotton, paper) are effective at buffering. Use these materials to help limit changes in an environment. By wrapping an object in a layer of unbleached muslin or paper and/or including buffering material such as silica gel packets within a well-sealed cabinet or exhibit case, you can provide a local climate for sensitive objects. Refer to *COG* 1/8: "Using Silica Gel in Microenvironments" for guidance on using silica gel. Discuss various options with a conservator.

4. *What is an active or mechanical control system?*

An active or mechanical control system uses specialized equipment to alter the temperature and moisture content of the air. It includes systems for heating, cooling, humidifying and dehumidifying the air. A well designed fixed mechanical system can maintain optimal temperature and RH levels, circulate air, and filter particulates and gases from the air.[iv]

Installing a well-designed heating, ventilation and air conditioning (HVAC) system to achieve and maintain appropriate RH and temperature levels, and filter particulates and gases from the air as described in this chapter can be challenging. In some cases, especially with historic structures, this approach may be detrimental to the structure itself.

Before embarking on a program to install, upgrade, or design a new HVAC system, assemble a team of experts and plan a system that protects both the collections and the structure housing the collection. Choose team members with expertise in collections care, historic structure preservation, and mechanical, electrical, and structural engineering. Information from your ongoing monitoring program allows your team to design a practical system that will preserve both the collection and the structure, as well as identify and address, on an ongoing basis, issues and needs of your climate control system.

Note: Use non-mechanical controls whenever possible and evaluate performance *before* adding a supplemental mechanical system.

5. *Can I use portable mechanical equipment to control temperature and relative humidity?*

In some cases, you may choose to use portable humidifiers, dehumidifiers, heaters, and air conditioners. They are especially helpful in historic structures that cannot readily or should not accommodate an HVAC system. In the short-term, this equipment can improve the environment in a space holding collections. It is less expensive and invasive than installing a new HVAC system. Portable equipment can be used to create different climate zones within a space.

Be aware that portable equipment requires regular operation attention to add water (such as a portable humidifier) or have the water reservoir (such as portable dehumidifiers) regularly emptied. They must be closely monitored to prevent water damage or electrical fires and should be regularly cleaned. Consult a specialist to establish what is appropriate for the structure. Work with your team of experts to identify the most appropriate solution to your climate control issues. See H.8, Who should be involved in planning for an HVAC system?

- **Humidifiers** add moisture to the air. Use a humidifier in the winter to counteract the drying effect of a central heating system. Only use an unheated evaporative humidifier. This type of humidifier does not disperse minerals in the air, and if the humidistat (a switch that turns off the equipment when a certain RH is reached) malfunctions, it will not raise the RH level above a set point, such as 65%. Be aware that these humidifiers can increase moisture that may condense on surfaces such as cabinets, doors, windows, and walls. Consider adding an evaporative section with "face and bypass" dampers onto the air handling system to more closely control the space conditions.

- **Dehumidifiers** remove moisture from the air and lower the RH. Do not use this equipment as a permanent corrective measure. Instead, find out why the air is so damp and work to remove the source of the water or moisture.

Be sure air is well circulated when using portable equipment. Fans may be needed for circulation. In consultation with a mechanical engineer, select the size and number of dehumidifiers and humidifiers based on the size of the space, the air exchange rate, differences between the inside and outside of the building, and the number of people using the room. See *Preservation Brief* 24, "Heating Ventilating, and Cooling Historic Buildings: Problems and Recommended Approaches" for more information.

6. What are humidistatically controlled heating and ventilation systems?

Humidistatic control is a way to automatically control RH in a building by taking advantage of the inverse relationship between temperature and RH. Humidistatically controlled heating is based on the principle that it is possible to maintain a stable RH by manipulating and varying the temperature.

A humidistat sensor adjusts the temperature up and down to maintain a stable RH. If the RH rises above a set point, the heat is turned on until the RH drops back down. However, using this system, temperatures can drop very low or rise very high, so this type of environmental control system is best used in areas that are infrequently accessed and that do not house any sensitive objects.

Humidistatically controlled ventilation is used in areas with high or low relative humidity. If interior RH is lower than exterior RH, dampers are opened by sensors and the air is circulated through the building. If exterior RH is too high, the dampers remain closed. N**ote:** This type of system is designed for building protection only.

Both of these techniques may be cost effective ways to improve the environment in historic structures that were not built to house museum collections. If you are considering using humidistatic controls work with an engineer or architect who has experience with this type of equipment and with a conservator as collections are present.
Note: This type of control is not well suited for human comfort.

7. What is an HVAC system?

A heating, ventilation, and air-conditioning (HVAC) system is responsible for moving air through a structure and setting the desired temperature and RH. HVAC systems can be imagined as a continuous loop of air that moves into and through an enclosed space before returning to its starting point, where properties of the air are changed to maintain the desired climate conditions in the spaces.[v] HVAC systems manage moisture by controlling the dew point within a structure and managing the air that enters the structure. These systems can both humidify and dehumidify the air.

- **Humidification.** There are two types of humidifiers used in air handling systems:

– *Steam humidifiers* in which a heat source is used to evaporate the water and add it directly to the air

– *Evaporative humidifiers* in which the air to be humidified is used as the heat source to evaporate the water and add it directly to the air. Because the air itself is the heat source for evaporation, this type also cools the air as it adds moisture.

- **Dehumidification.** Dehumidification can be accomplished in two ways:

– *Refrigerant dehumidifiers* work on the same principle as a refrigerator by cooling and reheating the air. Cooling the air lowers the vapor pressure of the water vapor causing it to condense within the machine. When air hits a cool coil, the moisture in the air condenses and it reaches a relative humidity of 100%. The air is then reheated to bring RH down to an appropriate level.

– *Desiccant dehumidifiers* force air through a moisture-absorbing material (like lithium chloride) to absorb moisture. In a separate step hot air is blown over the desiccant to regenerate (dry) it.

8. Who should be involved in planning for an HVAC system?

Use a team approach when planning to install or upgrade an HVAC system. Consult with the park maintenance staff, regional curator, preservation specialist, conservator, and mechanical engineer with experienced in installing HVACs in museums. In consultation with these specialists, develop the HVAC system that includes installation, commissioning and long term maintenance of the system.

Monitor and evaluate the climate within the structure for at least a year to determine if a new or upgraded HVAC is necessary.

9. What is HVAC system commissioning and when is it necessary?

Commissioning an HVAC system allows you to determine whether the system is maintaining the target RH and temperature set points and if it is staying within allowable fluctuation ranges. To commission a new HVAC system you need to closely monitor and evaluate its performance for at least one year after installation. This will allow you to evaluate how the system performs through different weather conditions, seasons, and operating conditions. Commissioning ideally begins early in the design process and ends well after installation.

Be sure to include a defined commissioning period such as a year, in your purchase document and maintenance agreement, as well as a requirement to correct any system deficiencies or problems that present during the commissioning period.

System performance requires ongoing, monitoring and evaluation for the life of the system to ensure that it functions properly, maintains a stable climate with the set points and allowable fluctuations that you established, and that it responds appropriately to environmental changes.

10. What is the advantage of using a prefabricated modular structure?

A prefabricated modular structure is a well-sealed; often vapor tight, highly insulated structure that can be constructed within a larger space to maintain levels of temperature and RH that would otherwise be unsuitable for the surrounding structure. If a structure cannot maintain the temperature and RH levels required for preserving an entire collection, consider storing the collection in a prefabricated modular structure. This method is especially advantageous for historic structures.

Make sure that the structure will be able to withstand the added weight of a prefabricated modular structure. See *COG* 4/7: "Museum Collection Storage Space: Is an Insulated Modular Structure Right for your Collection?" for more information. Monitor, evaluate and commission the system as you would an HVAC system. If the non-mechanical controls are insufficient, implement a mechanical system to create the appropriate climate. See *COG* 4/8: "Selecting Environmental Control Systems for Insulated Modular Structures" for more information.

11. *What is the time-weighted preservation index (TWPI)?*

The time-weighted preservation index is a mathematical model developed to estimate how long some organic materials will last at certain temperature and RH levels

The TWPI was developed specifically for paper-based collections and is more commonly used for archives and libraries. It may not be appropriate for mixed collections found in many NPS parks. Its use in various types of collections is being researched. Consult with a paper conservator to determine if it is appropriate to use for storage of your paper and photo collections that are housed separately from the general collections. The TWPI allows you to make educated decisions choosing a set point for RH and temperature for certain types of collections, such as paper materials. For more information, see the Image Permanence Institute's preservation metrics web page.

I. Light

Light is an agent of deterioration that causes irreparable damage to museum objects. It causes fading, darkening, yellowing, embrittlement, stiffening, and many other chemical and physical changes. This section gives an overview of the nature of light. It provides lighting standards for museum objects and information on how to prevent damage caused by natural or artificial light to your collections. It includes sections on how to monitor and control lights, as well as equipment and techniques on how to document and interpret monitoring data.

Damage to all museum objects that results from exposure to light, even at low levels, is cumulative and irreversible. Many materials, including organic materials are particularly sensitive to light damage, such as paper, inks, feathers, furs, leather and skins, photographs, textiles, works on papers and wooden objects. Objects on exhibit in furnished historic structures and visitor centers are at great risk of light damage. Typically, these structures have many windows and objects on display in historic structures are usually not contained within a protective enclosure. Follow recommendations outlined in this chapter to avoid and mitigate damage that results from exposure to light.

Consult with a lighting specialist and conservator when developing a lighting plan for collections housed in exhibit galleries and furnished historic structures.

1. *What is light?*

Light is a form of energy that stimulates our sense of vision. This energy has both electrical and magnetic properties, and is known as electromagnetic radiation. To help visualize this energy, imagine a stone dropped in a pond. The energy from that stone causes the water to flow out in waves. Light acts the same way. We can measure the "wavelength" (the length from the top of each wave to the next) to measure the energy of the light. The unit of measurement is the nanometer (1 nanometer [nm] equals 1 thousand millionth of a meter).

The spectrum of electromagnetic radiation can be divided into parts based on the wavelength:

- **Ultraviolet (UV)** on one end has very short wavelengths (300 - 400 nm) and high energy. UV is not visible to the human eye.
- **Visible light** portion of the spectrum lies between UV and IR, with longer wavelengths between 400 – 760 nm. Humans can see light in this band of the spectrum.
- **Infrared (IR)** wavelengths on the other end of the spectrum starts at about760 nm. We perceive IR as heat. It is not visible to the human eye.

While UV radiation is the most damaging to museum objects, visible and IR radiation also cause damage to museum objects. Light damage is irreversible and cumulative.

Different light sources contain varying amounts of UV, visible light and IR. Daylight or natural light contains all three. Many types of museum lighting (daylight, fluorescent lamps, fiber optics, and quartz tungsten-halogen lamps) emit varying degrees of UV radiation. Development in lighting technology has made it possible to light objects without exposure to UV, such as light-emitting diodes (LEDs). See Section J.8, What are the advantages and disadvantages of using light-emitting diodes (LEDs)?

The energy in light reacts with the molecules in objects causing physical and chemical changes. Because humans only need the visible portion of the spectrum to see, we can limit the amount of energy that contacts objects by excluding UV and IR and minimizing visible light that reaches objects from light sources. Equipment, materials, and techniques are widely available to block, eliminate or reduce these agents of deterioration and that are described in this section.

Eliminate all UV in spaces housing museum objects on exhibit, in storage, and in work areas.

2. *How is light measured?*

The strength or intensity of visible light is referred to as the *illumination level* or *illuminance*. Illuminance is measured in *lux* or *foot-candle*. *Lux* is the amount of light flowing out from a source (candle) that reaches and falls on one square meter. *Foot-candle,* the English or Imperial measurement, is one lumen per square foot. One foot-candle equals about 10 lux. Museums use lux or foot-candles as units of measure.

Illuminance is measured in museums because we are concerned with the *light energy that falls on objects*, not how much light energy comes from the source. When measuring light levels (see Section G), hold the meter at the surface of the object to catch the light that is reaching that surface.

UV is measured in units of microwatts (of UV) per lumen (of light), abbreviated to µwatts/lumen. While museums use lux or foot-candles as units of measure, it can also be measured in milliwatts per square meter. This ratio indicates the power of UV relative to the quantity or intensity of visible light. To avoid damage, eliminate all UV radiation with emissions below 10 µwatts/lumen (10 mW/l). This can be achieved by blocking natural radiation completely and by using UV filtration and absorption materials. See Section J, Monitoring and Controlling Light for more information.

3. *What deterioration does light cause?*

When light shines on an object, physical and/or chemical changes begin to occur on the exposed surface. Energy from light breaks molecular bonds or rearranges atoms in an object, chemically altering it. As the object's molecules absorb the light energy, the change that occurs is known as photochemical deterioration.

Ultraviolet radiation, the shorter the wavelength (*Ultraviolet [UV]* within the spectrum), the more energy in the light, and the more damaging to objects. This damage can be rapid and severe, or slow and slight. Even small amounts of light will cause irreversible and cumulative damage**.** Some examples of irreversible light damage include:

- Discoloration, including yellowing and fading
- weakening and embrittlement

Infrared light raises object temperature, increasing the speed and frequency of chemical reactions, and should also be eliminated. If lighting is too close to, or focused on an object, IR can raise the temperature. It may also lower the water content of porous materials. There is heat buildup from:

- sunlight
- incandescent spotlights
- quartz halogen lights
- fluorescent ballasts
- lights in closed cases

Design exhibits so there is no heat buildup from IR generated by lights or lighting equipment. See Section J for ways to monitor light and protect collections from light damage.

4. *What are the light standards?*

Protect collections from damage caused by natural and artificial light by eliminating UV and IR, reducing the amount of light (minimizing visible light and keeping artificial light levels low.) The radiation standards for visible light levels, maximum annual exposure for visible light levels and UV levels for different materials are provided below.

Exhibit lighting requirements differ from storage lighting requirements. Objects on exhibit are exposed to light over time and visitors need to be able to see objects on exhibit.

Balance preservation concerns with those of providing visibility. However, preservation concerns must take precedence over access considerations to ensure that the object is available for future generations.

Consult with a conservator as you develop or update lighting for museum, visitor center and furnished historic interiors.

Visible Light Levels	**Materials**
50 lux (5 foot-candles) or less (For extremely fragile light sensitive objects, reduce exposure time by covering exhibit case and allow the public to ‘peek’)	*Extremely light-sensitive materials;* organic materials including, biological specimens, blue prints, basketry, books, drawings, dyed organic materials including plant materials (extremely fugitive pigments and dyes), feathers, fur, leather, manuscripts, paper, parchment, photographs (including albumen and tinted photographs), plastics, prints, tapestries, textiles, tortoiseshell, watercolors on any medium, wall paper, works of art on paper
100 lux (10 foot-candles) or less	*Light sensitive materials*; lacquer ware, tempera paintings, undyed organic materials (basketry, bone, horn, ivory, plant materials, teeth)
150 lux (15 foot-candles) or less	*Moderately sensitive materials*; paintings (oil, acrylics) furniture, objects with painted surfaces, polychrome panels, finished wood surfaces
300 lux (30 foot-candles)	*Non sensitive materials;* metals, stone, ceramics, some glass

Figure 4.6: Standards for Visible Light Levels (Source[vi])

5. *Does length of exposure to light matter?*

Even small amounts of light will cause damage to most materials. The rate of damage is proportional to the illumination level multiplied by the time of exposure. Therefore, it is essential for you to determine how much exposure an object on exhibit should be subjected to, and over what period of time. Use the Figures 4.6 through 4.8 to calculate how long an object should be on exhibit.

Limit damage from light by reducing the amount of light and the exposure time.

When considering light damage to an object, note that the rate of deterioration is directly proportional to the illumination level multiplied by the time of exposure. Think of it as an equation:

Deterioration = Level of Illumination x Exposure (Exhibit) Time

Expressing light damage as an equation demonstrates that to reduce deterioration, *both* the level of illumination and the duration of exposure must be reduced. When determining-how to limit damage to objects exposed to light, keep in mind the "reciprocity law that states:"

Low light levels for extended periods cause the same amount of damage as high light levels for brief periods.

A dyed textile or taxidermy mount on exhibit for six months will fade about half as much as it would if left on exhibit for one year under the same conditions. Some types of photochemically induced deterioration will continue even after an object is removed from light. See Section J for guidance on controlling visible, UV and IR light levels.
Calculate the exposure time using the following equation:

Duration of exposure x Intensity = Total Exposure

For example; 200 hours x 60 lux = 12,000 lux hours
60 hours x 200 lux = 12,000 lux hours

Maximum Annual Exposure for Visible Light Levels	**Materials**
55,000 lux hours (15 lux x 10 hours x 365 days)	*Extremely sensitive materials* such as blue prints, books, drawings, dyed organic materials
180, 000 lux hours (50 lux x 10 hours x 365 days)	*Sensitive materials* including organic materials (biological specimens, feathers, fur, leather, manuscripts, paper, parchment, photographs, prints, tapestries, textiles, tortoiseshell, works on

	paper, watercolors on any medium, wall paper), plastics
365,000 lux hours (100 lux x 10 hours x 365 days)	*Moderately sensitive* materials including lacquer ware, undyed organic materials (bone, horn, ivory, uncolored plant materials)
550,000 lux hours (150 lux x 10 hours x 365 days)	*Somewhat sensitive* materials including paintings (oil, egg tempera, acrylics) furniture, painted surfaces, finished wood surfaces
730,000 lux hours (300 lux x 10 hours x 365 days)	Metals, stone, ceramics and some glass

Figure 4.7. Standards for Maximum Annual Exposure for Visible Light Levels (Source[vii])

6. *How long should objects be on exhibit and at what light levels?*

Follow the exposure duration limit recommendations provided in Figure 4.8 when placing objects on exhibit. Include a rotation schedule so that objects do not exceed the recommended exposure guidelines.

Materials	**Exposure Duration Limit**	**Light Level**
Extremely light sensitive materials (1) albumen & tinted photographs, blueprints, extremely fugitive pigments & dyes, highly degraded paper & silk, pre-19th century Japanese prints with color	3 months over 5 years	5 footcandles (50 lux)
Extremely light sensitive materials (2) books, organic materials such as biological specimens, dyed basketry or other plant material, feathers, fur, leather, manuscripts, parchment, , paper (documents, works on paper, wall paper), paintings with organic pigments and dyes, plastics, tortoiseshell, historic photographs including carte de visite, tapestries, textiles in poor condition or with organic dyes, watercolors on any medium	6 months over 5 years	5 footcandles (50 lux)
Light sensitive materials organic materials including bone, horn, ivory, uncolored basketry or plant materials, teeth, paintings with mineral pigments, leather (dyed), pastels, textiles in good condition or with aniline dyes, lacquerware, tempera paintings	12 months over 5 years	10 footcandles (100 lux)
Moderately sensitive materials enamels, furniture and finished wood surfaces, leather (undyed), objects with painted surfaces, paintings (oil, acrylics)	24 months over 5 years	15 footcandles (150 lux)
Non sensitive materials; ceramics glass, metals, stone, metal and stone jewelry	unlimited	unlimited

Figure 4.8. Exposure Duration Limit Recommendations (Source [viii])

Consider the variables noted below before permitting objects to be exhibited or used in research, and take into account the following:

- light sensitivity of the object
- time of exposure
- light level
- type of use
- color and contrast of object

The human eye can adapt to a wide variety of lighting levels, so a low light level should not pose visibility problems. However, the eye requires time to adjust when moving from a bright area to a more dimly lighted space. This is particularly apparent when moving from daylight or brightly lit interiors into a darker exhibit area. When developing exhibit spaces, gradually decrease lighting from the entrance so visitors' eyes have time to adjust. Keep light levels below levels noted in Figure 4.6 through 4.8.

For example, if a researcher needs to examine fine detail in the weave of a textile, but will only be working on the object for a few hours, and the object is not fragile and rarely exposed to light, you can allow for a *slightly* higher level light to be used.

Light sensitive objects require very low light levels, short exposure times and no UV.

See Figures 4.6 - 4.8.for lighting standards and guidelines.

Note: Staying below these exposures levels does not prevent light damage. There is no minimum level where damage will not occur. However, managing light levels enables you to minimize risk somewhat while balancing collection preservation with accessibility.

J. Monitoring and Controlling Light

Ongoing monitoring, documentation and evaluation of light levels in all areas that house collections over time will allow you to take appropriate control actions. Monitoring and documenting light levels allows you to:

- identify areas of high light levels that need to be corrected
- determine what light levels are at different times of the day, during different seasons, and during various events

- take measurements when changing or installing new lighting fixtures to be sure the changes are within recommended levels

- be sure that light levels are at required levels and that UV blocking materials are still effective, that there is no IR and that visible light is appropriately controlled

1. What equipment is used to monitor light levels?

Monitor light levels using specialized equipment. Use a visible light meter to measure visible light and a UV meter to measure ultraviolet light. Use a thermometer to measure heat buildup from IR. Different meters are available for measuring visible and UV light from various vendors. Some dataloggers also include sensors for monitoring light.

- **Visible Light Meter***:* Use a visible light meter to measure visible light, namely, the visible portion of the electromagnetic spectrum. When purchasing a new meter, be sure to purchase one that measures in the standard unit, lux. The meter should be sensitive enough to measure light levels as low as 15 lux with a reasonable degree of accuracy (10% or better).

- **Ultraviolet Meter***:* Use a UV meter to measuring UV levels. These meters give UV readings in microwatts per lumen.

If a UV meter is not available, assume that unfiltered sunlight, fluorescent and quartz-halogen lamps emit unacceptable and destructive UV radiation.

Use a standard set of procedures when monitoring light levels with both meters. Aim the sensor toward the light source to catch the light hitting the object you are monitoring. Be sure no shadows from your hand or body are in the way. Make sure the sensor is parallel to the surface of the object and aimed toward the light source. If the object is larger than about one foot square, take several readings. Before using any equipment, read the manufacturer's instructions for operation and maintenance.

- **ISO's Blue Wool standard cards** can be used to measure light damage. They are specially dyed textiles made so that the most sensitive sample fades in half the time needed to fade the next most sensitive sample. There are eight samples to a set. You can use them in two ways:

  – Place one set of standards at the place you want to measure. Place another set in total darkness.

  – Secure aluminum foil over one half of a set of standards and put out in the places you want to measure.

  By comparing the two sets of standards, or two halves of one set, you can determine that light damage is likely at the levels/rates of deterioration measured. The standards will not help you estimate how much exposure to light a material will withstand in a particular situation. Blue Wool standards can be effectively used to bolster your case that light damage is occurring and that changes are needed to protect museum objects. They are available from conservation suppliers.

The *Light Damage Calculator* developed by the Canadian Conservation Institute allows you to estimate the fading of colors on selected materials that have been exposed to light.

2. What steps do I take to develop a lighting improvement plan?

Develop a lighting improvement plan for collections in storage and on exhibit. The plan includes the gathering of information and how to determine if a lighting problem exists, what the cause is, and what actions are needed to correct the problem, and determining if those actions were effective. Follow the steps below to develop a lighting improvement plan. Guidance on how to implement the plan is described in this section.

- **Gather information**

Document the following *lighting information*:

– types of existing lighting fixtures, ballasts, and filters

– movement of sunlight into the room(s) throughout the day

– seasonal variations in light

– events such as filming or photography

– location of light monitoring sites

– light exclusion and filtering materials and where they are installed

– gather baseline and ongoing lighting information

Document the following *collections information*:

– identify objects that are most susceptible to light damage and their level of sensitivity, such as paper, photographs, feathers and other organic materials

– optimal exposure time for material types

– how light may affect the objects once you have identified the types of light and variations in lighting

– floor plan for each exhibit or storage space that indicates the location of each monitoring site

– establish monitoring sites near susceptible objects and use these same sites for each monitoring session

– abandon monitoring old sites and establish new ones as conditions change

- **Evaluate monitoring data**

– do ongoing monitoring to make sure the plan is effective

– record data on the Light and Heat Measurement Record illustrated in Figure 4.9.

- **Take corrective actions and document**

– determine if corrective actions are effective

– Take appropriate action as needed

Use a range of methods and equipment to minimize the risk of light damage to your collections. Monitor and document light levels before and after taking any action to be sure that your changes have been effective.

3. How do I protect collections from light damage?

Use a range of methods and equipment to minimize the risk of light damage to your collections. Monitor and document light levels before and after taking any action to be sure that your changes have been effective.

- **Eliminate all ultraviolet radiation (UV)**

– Exclude exterior windows in new purpose-built structures that house collections

– Block windows in adapted spaces or structures that house collections.

– Install UV filtering material over all windows in furnished historic structures, visitor centers and exhibit galleries in consultation with a conservator and historic architect.

– Install glazed, double glazed, interior storm windows or U-value windows with UV filtering capability where appropriate.

– Use UV filtered or coated light sources.

– Use UV filtering glass or acrylic when framing documents and works of art.

- Take ongoing readings, including at different times of the day and various seasons, to ensure that UV blocking materials are still effective.

  For information on UV filtering materials, see question 4 below.

- **Eliminate infrared radiation and/or heat buildup**

- Eliminate sunlight by eliminating or blocking windows in storage areas.

- Use window coverings and/or filters in historic furnished interiors, galleries and visitor centers.

- Do not use incandescent spotlights.

- Keep lights and ballasts outside exhibit cases.

- Use filters for artificial lighting to minimize IR build up.

- Keep light sources away from objects. If lighting is too close to or focused on an object, IR can raise the temperature. It may also lower the water content of porous materials.

- Use effective air circulation systems (such as fans and air conditioners) to help control heat buildup.

- **Mitigate and control daylight and artificial light**

- Lower light intensity and duration in exhibit and storage areas.

- Install light filtering materials on all windows and light sources. These include UV blinds or sheets of UV blocking glass. Do not use reflective films or tints in historic structures as they convey an inappropriate appearance

- Install window coverings such as blinds, shades, curtains, shutters, and exterior awnings.

- Locate objects on exhibit away from daylight sources such as windows.

- Light sensitive objects with fiber optics or LEDs. Do not use daylight to illuminate collections on exhibit.

- In areas where objects are displayed:

- implement a schedule in consultation with interpretation and maintenance staff to keep blinds, shutters, and curtains drawn or lowered to prevent and/or minimize visible light from reaching objects on display.

- Work with intepretive staff to ensure that windows are covered, particularly during period of intense sunlight/UV radiation, such as between 11am - 3 pm.
- Keep curtains and blinds closed while visitors are not present.
- As necessary, interpret a furnished historic room as an evening setting and provide intepretive information about traditional use of these coverings.

– Use:

- opaque dust covers (such as cotton muslin or Gortex®) to cover light-sensitive objects
- rugs to protect floor coverings.
- dust covers when visitors are not present for extended periods. These are useful in storage areas and exhibit areas that are not open to the public for part of the year.

- **Minimize and control light intensity**

– Lower light levels and keep as low as possible. Follow lighting level standards in Section 4.4, Standards for visible light levels.

– Step electric voltage down, including bulb wattage, in consultation with facilities management.

– Replace lighting fixtures to block UV and IR build up by installing LEDs where possible.

– Use fewer fixtures where possible

- **Reduce exposure time to light sources**

– Limit exposure time in accordance with times noted in Figure 4.7. Standards for maximum annual exposure for visible light levels.

– Install motion detectors in work and exhibit areas that activate lighting only when people are present.

– Implement a regular exhibition rotation schedule for light sensitive objects on exhibit, no longer than 3 to 6 months under controlled lighting conditions. See question 8, What is the benefit of rotating objects on exhibit? for more information.

– Use reproductions of highly sensitive materials on exhibit.

House objects in closed cases and cabinets, enclosures, boxes, and folders to minimize light exposure in storage and work areas.

4. What kinds of UV filters can I use?

Several types of UV filtering materials can be used in storage and exhibit areas, and in furnished historic structures. Work with facilities management and consult with a historic architect to select the most appropriate materials for a furnished historic structure.

There is a wide range of UV filters that can be used on structures, exhibit cases and on framed works of art. They include:

– UV filtering glass or acrylic in windows and for framed works of art

– UV filtering double or secondary glazed windows

– UV filtering panels suspended or mounted over or in front of unfiltered glass that permit light penetration

– UV filtering interior storm windows

– UV filtering blinds, window shades or drapes for windows. Do not use film on historic windows as it may damage the historic glass. It also has a finite usage life and needs to be replaced on a regular schedule.

– UV filtered fluorescent tubes and filter sleeves for fluorescent tubes

Note: The plastic material that carries the UV filtering coating often breaks down faster than the filtering chemical. Replace filters periodically, and whenever they begin to turn yellow or crack. Monitor UV radiation at least every five years to be sure the filtering material is still effective.

Deploy an effective lighting system to protect your collection on exhibit. Work with a conservator to implement the best available lighting for your furnished historic structure.

See *Preservation Tech Notes*, Museum Collections Number 2, Reducing Visible and Ultraviolet Light Damage to Interior Wood Finishes, *COG* 3/10: "Choosing UV Filtering Window Films," *MH-III*, Chapter 7, Section H, Exhibit Conservation and Section I, Preserving and Protecting Objects in the Exhibit Process and J, Exhibit Case Design, Using Museum Collections in Exhibits, and the NPS Harpers Ferry Center, Exhibit Conservation web site.

Note: Balance access with preservation needs but make sure that preservation takes precedence to ensure that NPS collections are available for future generations.

5. What should I know about photography, flash photography, and photocopying and collections preservation?

Lighting used for photography, videography, and photocopy machines can cause excessive light exposure and heat buildup. To minimize damage, implement the guidelines noted below.

General photography and videography(filming)

- Avoid overheating objects with studio lights, especially light sensitive materials.
- Create a separate area or space for photography.
- Request heat absorbing light filters and be sure the area is well-ventilated with fans or air conditioners when photography is allowed in museum areas.
- Turn lights off whenever photography or filming is not taking place. If lighted rehearsals are necessary, use dummy objects until the final filming or photography will take place.

Flash photography and photocopying

Conservation research indicates that excessive flash photography and photocopying of light sensitive materials causes damage. Popular or iconic museum objects are likely to be heavily photographed or photocopied and therefore subject to fading and other damage. Certain materials such as handwritten documents, daguerreotypes and blueprints are particularly light sensitive.

You should:

- prohibit flash photography for light sensitive materials on exhibit
- limit photocopying of light sensitive materials

However, in order to provide access to these materials, make a master or reproduction images and/or photocopies readily available. See question 5 below.

For other non-light sensitive materials, flash photography can be permitted, as the exposure period is very short. Many museums permit photography but do not allow flash photography to avoid disturbing visitors. See *MH-III*, Chapter 6, Section D, Filming and Photography in Spaces Housing Museum Collections.

6. How do I limit damage from research use?

When collections, including objects, archival materials, and natural history specimens are used by researchers, they are exposed to light. Set up separate work spaces and research rooms so that your entire collection is not exposed to light when people are working with individual objects. Incorporate the following practices into research room use to limit the damage that occurs from this use.

- Develop procedures so that collection items are exposed to light only while the researcher is using them.

– House documents in containers, including boxes and folders.

– Remove objects from cabinets only when the researcher is ready to work.

- Limit the time the object is exposed to light and set a maximum lux level based on the object's sensitivty

- Limit the number of times an individual document can be photocopied. Create a copy of frequently requested archival materials and distribute as necessary.

- Take high quality photographs of frequently requested objects and make available in various formats, including online, as necessary.

- Limit the use of additional light sources, such a flash photography as noted question 4 above.

See *MH-III*, Appendix D: Planning a Research Space, and *COG* 19/7: "Archives: Reference Photocopying," and 4/14: "Planning a Research Space," for more information on limiting light damage from collection use.

7. What data should I collect to complete Light and Heat Measurement Record?

Complete the Light and Heat Measurement Record shown in Figure 4.9. Use building floor plans in conjunction with this record. Analyze the data from the Light and Heat Measurement Record and seek answers to questions below to determine how to minimize the damage from light. Consult the regional curator and/or a conservator when doing this evaluation.

- Which areas have acceptable levels of light for the objects?

- How long have objects been on exhibit in these areas?

- Do the objects on exhibit how signs of damage? Remember, not all damage can be detected by visual inspection.

- Which areas have light levels that are too high? Take corrective actions and determine whether these changes have helped. For example, if UV filtering blinds are installed over glass window panes, monitor for UV before and after installation

- Has the UV been eliminated? Has it reduced visible light?

- What are the light levels in storage?

- How often are collections in storage used? Where and how are they used? What levels and duration of light exposure do they normally receive?

- Can light levels be reduced in research rooms to improve preservation and still provide adequate access?

- How often are archival collections copied? Is there ‘duplication master’ so that originals do not have to be continuously copied?

- Are you maintaining and evaluating a record of the data you collect? This information will help you make a case for needed changes in lighting or removal of threatened objects. Keep a permanent file of all light monitoring data.

- How can I work with interpretation staff to minimize light damage to collections on exhibit in furnished historic structures, visitor centers and museums?

NATIONAL PARK SERVICE LIGHT AND HEAT MEASUREMENT RECORD					
Structure: *Family Home*					
Date	**Time**	**Location** (of object being measured)	**UV Reading (uw/ lumen)**	**LUX Reading**	**Room Temperature**
4/26/2014	11:00 am	Wooden buffet in dining room opposite the bay window Comment: Cloudy day, sheers drawn over UV blind, drapes open	10	75	68
5/24/2014	11:30 am	Wooden buffet in dining room opposite the bay window Comment: Bright and hot, sheers drawn over UV blind, drapes closed	10	75	72
6/26/2014	11:15 am	Wooden buffet in dining room opposite the bay window Comment: Bright and hot, sheers drawn over UV blind, drapes closed	10	78	73

Figure 4.9. Sample Light and Heat Measurement Record

8. What is the benefit of rotating objects on exhibit?

Rotating objects on exhibit allows you to limit light exposure and thereby limit light damage. Create a rotation plan for light sensitive objects on exhibit in the museum, visitor center or furnished historic structure.

Consider the duration and intensity of exposure and the fragility of the material when developing the schedule. Certain materials, such as paper and textiles are extremely light sensitive and should be exhibited at 5 footcandles for short periods of time and rotated regularly. For example, display a rare historic handwritten letter in a UV free exhibit case for no longer than 3 months to avoid irreversible damage. A more robust document should be rotated off exhibit after 6 months, that is, it should not be on exhibit longer than 6 months. Display sensitive objects under low lighting levels.

If you are unable to lower light levels or need to have materials on exhibit beyond recommended times, arrange to exhibit facsimiles and reproductions in place of the museum object. Make fascimiles of extremely sensitive materials such as handwritten diaries or daguerretypes so as not to damage the original object. Use this as a opportunity to educate the public about object preservation by including this information in an exhibit caption or as part of the interpretive tour narrative.

See Figures 4.6 through 4.8 for recommended times and levels, and *MH-III*, Chapter 7, Section I, 4, How do I balance exhibit lighting with preservation requirements?

LEDs (light-emitting diodes) produce light through the movement of electrons through semiconductor material. LEDs are widely used in museums as they are energy efficient and sustainable, do not emit UV, and emit little or no infrared.

9. What are the advantages and disadvantages of using Light-Emitting Diodes (LEDs)?

Because they have a long life span compared to many other light sources, maintenance costs are lowered. LEDs provide immediate, full light when used with motion sensors, making them a viable option for less-used spaces. LED bulbs are point sources; they emit light in a specific direction, and provide effective lighting. Many lighting fixtures can be retrofitted with LED bulbs, while permitting retention of historic fixtures.

Advantages of using LEDs are noted below. LEDs:

- do not emit UV and very little IR.
- are energy efficient (they remain cool)
- use low voltage
- have a long life

- are durable
- do not contain mercury or other toxic chemicals
- are flexible and easy to install
- readily capable of focusing light on a specific location

Disadvantages of using LEDs include:

- LEDs can be problematic in true color rendering and rendered color may change over time.
- Before burning out, the light, which is initially white, begins to color shift, affecting the appearance of the space and objects on exhibit. Bulbs do not all color shift at the same time or to the same hue, potentially causing a rainbow of color over objects and artwork.
- Installation costs are high, including the high cost of bulbs and in replacing fixtures that cannot be retrofitted.
- LED bulbs often do not work with existing dimmer technology on fixtures.
- When bulbs burn out, some may flash on and off, which can be disturbing to visitors.

Consult with a conservator to select the appropriate LEDs for your specific use. Be sure to select a company with a long and well-documented warranty plan.

K. Particulate and Gaseous Air Pollution

1. What is air pollution?

Air pollution comes from contaminants produced both outside and inside museums. Contaminants can be airborne, transferred by contact, or contained (inherent) within objects themselves. All have the potential to cause or exacerbate damage to museum objects.

Common pollutants include: dirt, which includes sharp silica crystals; grease, ash, and soot from industrial smoke; sulfur dioxide, hydrogen sulfide, and nitrogen dioxide from industrial pollution; formaldehyde, and formic and acetic acid from a wide variety of construction materials, off-gassing of some plastics; ozone from photocopy machines and printers; and many other materials that can damage museum collections.

Air pollutants are divided into two types:

- **particulate pollutants** such as dirt, dust, soot, ash, molds, heavy metal dust, asbestos, and other fibers

- **gaseous pollutants** such as sulfur dioxide, hydrogensulfide , nitrogen dioxide, formaldehyde, ozone, formic and acetic acids

Exposure to these pollutants may also have adverse health impacts on staff. Engineering controls such as local exhaust ventilation or the use of personal protective equipment may be necessary to minimize exposure. Staff should be trained on the recognition and control of exposure situations. Refer to Chapter 11, Curatorial Health and Safety for more information.

See Figure 4.10 for a list of some common forms of deterioration by air pollution.

2. What deterioration is caused by particulate air pollutants?

Particulate pollutants are solid particles suspended in the air that come both from outdoor and indoor sources. These particles are mainly dirt, dust, mold, pollen, and skin cells, though a variety of other materials are mixed in smaller amounts. The diameter of these pollutants is measured in microns (1/1,000,000 of a meter). Knowing the particulate size is important when determining the size of air filters to use in a building.

Some particles, such as silica, are abrasive. In addition, pollen, mold, and skin cells can be attractive to pests. Particulates can interact with gaseous pollutants and cause deterioration in three different ways. Particulates may be:

- a source for sulfates and nitrates (these particles readily become acidic on contact with moisture)

- a catalyst for chemical formation of acids from gases

- an attractant for moisture and gaseous pollutants

3. What deterioration is caused by gaseous air pollutants?

Gaseous pollutants are reactive chemicals that can attack museum objects. These pollutants come from both indoor and outdoor sources.

Outdoor or atmospheric pollutants are brought indoors through a structure's HVAC system or open windows. There are three main types of outdoor pollution:

- sulfur dioxide (SO_2) and hydrogen sulfide (H_2SO) produced by burning fossil fuels, sulfur bearing coal, and other organic materials

- nitrogen oxide (NO) and nitrogen dioxide (NO_2), produced by any kind of combustion, such as car exhaust as well

- ozone (O_3), produced by sunlight reacting with pollutants in the upper atmosphere

When sulfur and nitrogen compounds combine with moisture and other contaminants in the air, sulfuric acid or nitric acid is produced. This acid then causes deterioration in a wide variety of objects. Ozone reacts directly with the objects causing deterioration.

Indoor air pollution generally comes from new construction and building materials as well as new office furniture and other sources such as:

- wood, which can release acids
- plywood and particle board, which give off acids from wood and formaldehyde and acids from glues
- unsealed concrete, which releases minute alkaline particles
- some paints and varnishes, which release organic acids, peroxides, and organic solvents
- fabrics and carpeting with finishes, such as urea-formaldehyde, and wool fabrics that release sulfur compounds
- glues used to attach carpets, that can release formaldehyde
- plastics that release plasticizers and harmful degradation products such as phthalates and acids
- electric or light equipment, such as photocopy machines, printers, and some air filtering equipment, which release ozone.

Museum objects themselves may also contribute to indoor air pollution. For example, many plastics are inherently unstable and as they deteriorate they can give off acidic by-products, such as cellulose nitrate and diacetate plastic, used for film. See *COG* 8/4: “Care and Identification of Objects Made from Plastic” for more information. Other sources of pollutants from museum objects include:

- celluloid and other unstable plastics used to produce many 20th-century objects
- pyroxylin impregnated cloth used for book bindings
- residual fumigants and pesticides, such as ethylene oxide
- wool can release sulfur that will tarnish silver

Object Materials	Deterioration	Primary Air Pollutants	Environmental Factors Accelerating Damage
ceramics	damaged surface	acid gases	moisture
leather	weakening, powdered surface	sulfur oxides	mechanical wear
metals	corrosion/tarnishing	sulfur oxides and other acidic gases	water, oxygen, salts
paint	surface erosion, discoloration	sulfur oxides, hydrogen sulfide, ozone, particulates	water, sunlight, microorganisms
paper	embrittlement	sulfur oxides	moisture, mechanical wear
stone	surface erosion, discoloration	sulfur oxides and other acidic gases, particulates	water, temperature fluctuations, salt, vibration, microorganisms, carbon dioxide
textiles	weakened fibers, brittleness, soiling	sulfur oxides, nitrogen oxides, particulates	water, sunlight, mechanical wear
textile dyes and pigments	fading, color change	nitrogen oxides, ozone	sunlight
shell, eggshell	efflorescence or breakout of salts, "Byne's Disease"	acetic and formic acid	moisture

Figure 4.10. Deterioration of Museum Objects Caused by Air Pollution

L. Monitoring and Controlling Particulate and Gaseous Air Pollution

1. How do I recognize particulate and gaseous air pollution?

As with other agents of deterioration, monitor to identify whether or not air pollution is causing damage to collections that are in enclosed or open storage, on exhibit, or in transit. Take the following steps to identify and understand air pollution levels:

- **Inspect storage and exhibit spaces** (such as floors, open shelving, tops of cabinets, cases and tablesin addition to polished surfaces such as piano tops.) for dust. Note how much dust has built-up since the last cleaning. Watch for increased insect activity using your IPM program. Increased insect activity is often related to an unacceptable accumulation of dust.

- **Observe and note active corrosion on metal objects** for pollution from chlorides in coastal areas Chlorides will react with unpainted iron or steel objects, causing rust. In highly trafficked, industrial and some mining areas, sulphides will react with silver and copper to cause tarnish, and lead will corrode on exposure to acetic acid.

- **Observe and document a building's air control system and the nature of the structure**. Concrete walls and adobe are sources of high levels of dust. Some concrete dating from 1940-1975 contains asbestos, making it a health risk as well as a source of damaging particulates. Improperly filtered air intakes can transfer high levels of pollutants into museum spaces.

- **Identify exhibit cases, storage cabinets, and shelving** made out of unacceptable materials. These include untreated wood or painted wood that can offgas formaldehyde and acetic acid.

- **Monitor how much dust and dirt is tracked into spaces by visitors and employees.**

Also consider the surrounding air quality. Some parks have on-going air monitoring research, and you can contact the Environmental Protection Agency (EPA), Office of Air Quality Planning and Standards to obtain information on levels of ozone, sulfur dioxide, nitrogen dioxide, and particulates recorded in the park. This data will assist park staff in identifying potential pollutant problems that may exist.

Areas with high concentrations of gaseous and particulate air pollution should establish a program for monitoring signs of active deterioration on objects in museum storage and exhibit areas.

2. How do I monitor air pollution?

There are several ways to monitor air pollutants in museums. Each method has advantages and disadvantages. Different pollutants may require different methodologies. Investigate the monitor types and evaluate the information you want to recover. Consult with your regional curator and a conservator and refer to *COG* 8/5: "Monitoring Off-Gassing of Plastics" and other resources in the bibliography for more information.

Oddy tests: Oddy tests were developed by conservation scientists to evaluate materials that are used in contact with objects in storage or on exhibit. In this test, metal coupons (small samples of different metals) are placed in a closed container with the material being tested and a small amount of moisture. The container is slightly heated and after a set amount of time, the metal is examined for corrosion. The test provides an indication of how 'safe' a material is and whether or not it will cause deterioration in your collection. Problems with this test include:

- unusual reactions - as heat and moisture are raised in the container, reactions may occur that would not happen in a normal museum environment

- little reproducibility since it relies primarily on visual indicators, making results from this test widely variable

Passive sampling devices: These are devices that absorb particular pollutants. They are placed in the area you want to test for a period of time, and then removed and sent to a lab to be tested for presence and levels of pollutants. Each passive sampling device measures one type of pollutant. For example, one device will measure for formaldehyde, another for acetic acid. However, there are problems with these devices:

- They may require off-site analysis.

- The devices have varying sensitivities. Use devices that can detect gaseous pollutant in parts per billion (1:1,000,000,000 ppb) or lower levels.

A-D strips. These strips detect acetic acid. They were developed to detect and measure acetate film deterioration, or "vinegar syndrome," in film collections. They change color as the level of acidity increases. They are used to set priorities for film reformatting.

When monitoring for contaminants, take human health impacts into consideration. If there is concern about effects on museum objects, the effects on the museum staff should also be considered. Contact your safety officer or Bureau industrial hygienist for questions about personal exposure monitoring. If you believe direct measurement is needed, contact your regional curator for assistance.

3. *How do I minimize and control air pollution?*

Eliminate gaseous and particulate pollution to the lowest practical level. Do the following to reduce levels of air pollution:

- Keep areas housing collections clean and prevent dust accumulation by implementing a museum housekeeping plan that includes:

– Use high efficiency particulate air (HEPA) vacuums which trap more particulates. Regular vacuum cleaners exhaust many smaller particles into the air. See *MH-I*, Chapter 13, Housekeeping chapter and *COG* 1/6: "Choosing a Vacuum Cleaner for Use in Museum Collections."

– cleaning, and vacuming floors, tops of cabinets and exhibit cases in storage and exhibit areas

– keeping work surfaces clean

– work with custodial staff to keep all areas clean

- frequently clean tour routes to reduce dust deposition on objects

- for gaseous pollutants (SO2, ozone, formaldehyde, organic acids, etc.) consider carbon filtration.

- Separate office and curatorial work spaces from museum collections storage spaces. Areas that are not frequently accessed usually stay cleaner than high traffic areas.

- Place door mats at appropriate doorways, in particular, from the outside, to minimize tracking dirt into storage and exhibit areas. Clean mats regularly.

- Upgrade and maintain seals and weatherstripping around doors and windows to keep pollutants and pests out. Install door sweeps on doors where weatherstripping is impractical.

- House all objects, particularly, sensitive objects in well sealed and constructed exhibit cases and storage cabinets. Maintain sound gaskets on all storage cabinets. See resources in the bibliography for more information.

- Store archival materials in museum quality boxes, map cases, and folders.

- Use dust covers to protect objects on open shelving. Dust cover material should be chemically and physically non-damaging and provide as complete a dust seal as possible, while allowing easy access. Use clear polyethylene sheeting, unbleached cotton muslin, Tyvek®, or Gore-Tex®. See *COG* 4/2: "Dust Covers for Steel Shelving," for more information.

- Separate objects that offgas pollutants (such as cellulose nitrate negatives or objects, diacetate negatives, or hardwoods such as oak, birch or beechwood) from other objects. Store silver that is wrapped in acid -free tissue and then placed in anti-tarnish cloth bags. Exhibit silver with anti-tarnish strips or on a pedestal covered with anti-tarnish cloth.

- Store, exhibit, and transport objects in appropriate cases. Avoid using exhibit materials (for example, hardwoods) that offgas organic acids. The adhesives used in plywood and veneers may be a source of pollutants. See Figure 4.11 for a list of harmful and safe materials.

- In areas with high air pollution levels consider installing pollution filtering in your HVAC system. These filters extract gaseous and particulate pollutants before they get into a museum space. Work with HVAC engineers to design a system appropriate to your facility. Do not use filtering systems that generate damaging ozone.

Use portable air filters with activated-carbon filters to remove particulates from the air. These filters will also remove some gaseous pollutants. See NPS Tools of the Trade for more information.

Storage and Exhibit Construction Materials Known to Release Harmful Substances	
Materials	***Harmful Vapors***
wood (particularly oak, birch, beech)	organic acids
wood panel products	organic acids, formaldehyde
protein-based glues, wool, silk	volatile sulfides
vulcanized rubber	volatile sulfides
some dyes	sulfur compounds
cellulose nitrate	nitrogen oxides
cellulose acetate	acetic acid
Poly(vinyl chloride)	hydrogen chloride
polyurethanes	volatile additives
some photographic processes	acetic acid
coating materials	various volatile compounds
Storage and Exhibit Construction Materials That Appear to be Safe	
metals	
glass	
inorganic pigments	
polyethylene and polypropylene (test before use)	
acrylic solutions (some acrylic emulsions are suspect) applied as liquid	
polyester fibers	
cotton and linen	
[1.] Note: while these materials are generally considered safe, manufacturing processes may add coatings and additives that can damage museum collections. Testing is appropriate for certain materials.	

Figure 4.11. Storage and Exhibit Construction Materials Known to Release Harmful Substances and Materials that Appear to be Safe

M. List of Figures

N. Selected Bibliography

Ashley-Smith, Jonathan, Andreas Burmester and Melanie Eibl. Climate for Collections: Standards and Uncertainties. Postprints of the Munich Climate Conference. 2013.

The ABCs of Air Conditioning: A Primer of Air Conditioning Types and Methods American Association of Museums. PIC- Green.

American Institute for Conservation of Historic and Artistic Works and the Association for Preservation Technology. *New Orleans Charter for the Joint Preservation of Historic Structures and Artifacts*, 1992.

ASHRAE [American Society of Heating, Refrigerating, and Air-Conditioning Engineers]. Chapter 23, Museums, Galleries, Archives and Libraries, *ASHRAE Handbook: Heating, Ventilating, and Air-Conditioning Applications,* Atlanta. 2011.

Avrami, Erica, Kathleen Dardes, Marta de la Torre, Samuel Y. Harris, Michael Henry, and Wendy Claire Jessup, contributors. *The Conservation Assessment: A Proposed Model for Evaluating Museum Environmental Management Needs*. Los Angeles: Getty Conservation Institute, 1999.

British Standards Institute. Publically Available Specification PAS 198:2012. *Specification for managing environmental conditions for cultural collections.* 2012.

Canadian Conservation Institute. *Ten Agents of Deterioration*.

Cumberland, Donald C., Jr. "Museum Collection Storage Space: Is an Insulated Modular Structure Right for Your Collection?" *Conserve O Gram* 4/7. Washington DC: National Park Service, 1994.

_______. “Collection Storage-Making a Case for Microenvironments.” *CRM Supplement* 15, no. 4, 1992.

_______. “Selecting Environmental Control Systems for Insulated Modular Structures.” *Conserve O Gram* 4/8. Washington DC: National Park Service, 1994.

Cuttle, Christopher. “Damage to Museum Objects Due to Light Exposure.” *CIBSE National Lighting Conference*, 1996.

Druzik, R. James. *Illuminating Alternatives: Research in Museum Lighting*. The Getty Conservation Institute Newsletter 19, No 1. (Sprint 2004

Henry, Michael C. “The Heritage Building Envelope as a Passive and Active Climate Moderator: Opportunities and Issues in Reducing Dependency on Air Conditioning” from *Getty Conservation Institute*, *Experts' Roundtable on Sustainable Climate Management Strategies*, 2007.

Hensley, Jo Ellen, and Antonio Aguilar. “Improving Energy Efficiency in Historic Buildings,” *Preservation Brief 3*. Washington DC: National Park Service, 2011.

Himmelstein, Paul, and Barbara Appelbaum, “*An Overview of Light and Lighting in Historic Structures that House Collections*,” APT Bulletin XXXI, No. 1 (2000): 13-15.

______. “The Paradox of Artificial Lighting in Historic Structures,” in *The Conservation of Heritage Interiors*, The Canadian Conservation Institute and the Association for Preservation Technology International (2000): 157-160. http://barbaraappelbaumbooks.com/wp-content/uploads/paradox.pdf

Image Permanence Institute

______. *Seminar Reference Workbook for Sustainable Preservation Practices for Managing Storage Environments*. Version 1.4 - April 2011.

______. *Sustainable Practices for Managing Storage Environments*.

______. eClimate Notebook

Merritt, Jane. “Mold: Prevention of Growth in Museum Collections,” *Conserve O Gram* 3/4. Washington DC: National Park Service, 2007.

______. The Ideal Climate, Risk Management, the ASHRAE Chapter, Proofed Fluctuations, and Toward a Full Risk Analysis Model. The Getty Conservation Institute. Contribution to the Experts' Roundtable on Sustainable Climate Management Strategies. 2007

The National Trust. *Manual of Historic Housekeeping: Care and Conservation of Collections in Historic Houses*. Rev. ed. Swindon, UK: The National Trust, 2011.

North East Document Conservation Center. Protection from Light Damage. Preservation Leaflet 2.4

Park, Sharon C. "Heating, Ventilating, and Cooling Historic Buildings: Problems and Recommended Approaches." *Preservation Brief 24.* Washington, D.C. National Park Service, 1991.

Robinson, Kim. "Creating a Microclimate for Oversized Museum Objects," *Conserve O Gram* 4/4. Washington DC: National Park Service, 1993.

Senge, Dana K. "Creating a Microclimate Box for Metal Storage," *Conserve O Gram* 4/16. Washington DC: National Park Service, 2011.

Shelton, Sally Y. "Byne's "Disease:" How To Recognize, Handle And Store Affected Shells and Related Collections." *Conserve O Gram* 11/15. Washington DC: National Park Service, 2008

Raphael, Toby. *Exhibit Conservation Guidelines*. CD-ROM produced by Harpers Ferry Center. Harpers Ferry, W.V.: National Park Service, 1999.

Sheetz, Ron, and Charles E. Fisher. "Reducing Visible and Ultraviolet Light Damage to Interior Wood Finishes." *Preservation Tech Notes* 2. Washington, D.C.: National Park Service, 1990.

Voellinger, Theresa A. and Wagner, Sarah S. "Cold Storage for Photograph Collections – An Overview," *Conserve O Gram* 14/10. Washington DC: National Park Service, 2009.

Weintraub, Steven. "The Museum Environment: Transforming the Solution into a Problem." *Collections: A Journal for Museum and Archives Professionals* 2, no. 3 (February 2006): 195-218.

Weintraub, Steven, and Gordon O. Anson. "Natural Light in Museums: An Asset or Threat?" *Progressive Architecture* 5 (May 1990): 49-54.

. ______. "Use Ultraviolet Filters to Neutralize an Invisible Enemy." *Museum News* 69 (1991): 85-87

O. Endnotes

[i] This temperature range expands the NPS *Museum Handbook,* Part I, Ch. 4, Museum Collections Environment, (1999) guidance slightly, and is in accordance with the AIC Interim Guidelines endorsed by the Association of Art Museum Directors that states: **"**For the majority of cultural materials… a temperature range of 59 - 77ºF (15 - 25ºC), is acceptable." See the IIC declaration on Environmental Guidelines that cites the AIC guidelines, 26 Sep 2014.

[ii] The explanation of dew point's importance in Section F.2 has been adapted from information in the Image Permanence Institute's *Seminar Reference Workbook for Sustainable Preservation Practices for Managing Storage Environments, Section 1, Defining an Optimal and Sustainable Preservation Environment*. Courtesy, the Image Permanence Institute.

[iii] This RH range revises the NPS *Museum Handbook,* Part I, Ch. 4, Museum Collections Environment (1999). It is somewhat broader than that cited by AIC Interim Guidelines as endorsed by the Association of Art Museum Directors in order to accommodate the many climate zones in which NPS park collections are located and the RH ranges to which they have acclimated. The AIC Interim Guidelines state, "For the majority of cultural materials, a set point in the range of 45 - 55% relative humidity with an allowable drift of +/-5%, yielding a total annual range of 40% minimum to 60% maximum…" See the *IIC* declaration on Environmental Guidelines, Sep 26, 2014.

[iv] *The ABCs of Air Conditioning: A Primer of Air Conditioning Types and Methods,* American Association of Museums. PIC- Green. http://www.pic-green.net/home-2 outlines the types of air conditioning systems, introduces cooling load calculation, and compares the functioning of system types.

[v] The explanation of an HVAC system as a continuous loop in Section H.7 is drawn from the Image Permanence Institute's *Seminar Reference Workbook for Sustainable Preservation Practices for Managing Storage Environments.* Courtesy, the Image Permanence Institute.

[vi] Figure 4.6. Standard for Visible Light Levels. Sources: The NPS *Museum Handbook,* Part I, Chapter 4, Museum Collections Environment, (1999) guidance on standards for visible light levels was updated with information obtained from several sources, including the Winterthur Preventive Conservation Team, The George Washington University Museum Studies Program, Canadian Conservation Institute, and the Arthur M. Sackler Gallery and Freer Gallery of Art, Smithsonian Institution.

[vii] Figure 4.7. Standards for Maximum Annual Exposure for Visible Light Levels. Sources: NPS *Museum Handbook,* Part I, Chapter 4, Museum Collections Environment, 1999 was updated with information from the *Light Duration Guidelines for Exhibited Works of Art*, developed by The Arthur M. Sackler Gallery and Freer Gallery of Art, Smithsonian Institution, Courtesy The Arthur M. Sackler Gallery and Freer Gallery of Art, Smithsonian Institution.

[viii] Figure 4.8. Exposure Duration Limit Recommendations. Sources: Information from NPS *Museum Handbook* and NPS *Conserve O Grams* incorporated into, and expands information in the *Light Duration Guidelines for Exhibit Works of Art* developed by the Arthur M. Sackler Gallery and Freer Gallery of Art, Smithsonian Institution. Courtesy The Arthur M. Sackler Gallery and Freer Gallery of Art, Smithsonian Institution.

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