3-0 TEMPERATURE

> ***"Deterioration needs energy – either light or heat. Light is much more potent than heat in the museum."***
>
> ***– Garry Thomson*** [1]

Museum personnel for the most part understand the necessity of controlling temperature and maintaining uniform temperatures in gallery spaces. Modern HVAC systems are almost universal both for comfort and for conservation reasons. Setting temperature variation limits should be a function of conservation, determined by balancing the sensitivity of the museum's artifacts against operating costs. Generally, the closer temperature tolerances are held on an HVAC system, the more a system cycles off and on and the more expensive it is to run.

3-1 Artifact and Case Temperatures

Temperature effects the rate of all chemical reactions. This includes the chemical reactions between different materials in artifacts and the reactions of pollutants with these materials. In addition, there are a number of physical processes driven by temperature changes. Understanding these processes will help you to set guidelines for temperature variations within the museum. Unfortunately most discussions of temperature control and temperature cycles do not take into consideration the heat of conventional lighting sources. Temperature cycles in artifacts under conventional lighting can be several times those of the gallery air or HVAC system. Remember too, that each museum visitor is equivalent to a 300-watt radiant heater. Galleries will always be hotter during the day then at night and especially so during peak visitor periods.

Museum cases can greatly buffer temperature changes within a gallery. In actual measurements in a gallery space with a 6°F total temperature variation, library cases lit with fiber optic lighting with zero measured IR showed only 2°F total variation internally.[2] The case itself buffered internal temperature changes to roughly 33% of the gallery variation.

The "buffer" can also work in reverse. Cases can trap and contain heat when conventional lighting is used. One curator actually described his cases a

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[1] Garry Thomson, p. 4.

[2] The lighting was built into the case with a fiber optic projector built into the base and all luminaires inside the display area focused onto artifacts in the case.

"pizza ovens."[3] In actual measurements, ventilated library cases ran 10°F above gallery temperatures when equipped internally with two fluorescent lamps. Ballasts for these cases were mounted external to the case to reduce heat buildup. Incandescent lighting because of its greater IR output (even when installed in isolated light attics above a case) can exceed these temperatures. As glass is transparent to IR radiation, even external case lighting with tracklights will raise case temperatures.

3-2 Chemical Reaction

Increased temperature accelerates all forms of chemical damage. Absolute temperature has a dramatic impact on the effects of pollution on artifacts. Increased temperatures of cases or artifacts can also increase the activity of molds, mildews and insects. Chemical reactions double with every 18°F (10°C) increase in temperature.[4] Those reactions include everything from photochemical reactions to the actions of pollutants on artifacts.

Mark Roosa, Chief of the Conservation Division of the Library of Congress turns this around slightly for conservation applications. He points out that every ten degree reduction in temperature doubles the life of an object.[5] This is true. In examining temperature issues, remember that artifact temperature is more important (and often much higher) than air temperature.

3-3 Photomechanical Damage

Beside the increases in chemical reaction, there are a number of physical processes driven by heat. IR can be extremely destructive if not understood and controlled. For the most part these processes are driven by the radiant heating from lighting sources. Eliminating the heat source eliminates the major force driving these processes. If you couple removal of IR with the ability of an exhibit case to buffer mild temperature and humidity swings, simple, effective case filtering becomes practical. We will therefore consider these processes from the viewpoint of radiant IR energy from lighting.

3-4 Differential Heating

The first of these processes involves the stresses caused by radiant heating. The IR radiation in conventional lighting raises the temperature of the

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[3] Spenser, Ted to Hattie Bryant in Small Business School, Television Program 103 NoUVIR (San Diego, CA: Public Broadcasting System, 2000).

[4] Toby Raphael, B:3, p. 1.

[5] Mark Roosa, "Conservation Ideas," Roundtable at the Small Museum Association Winter Conference, Ocean City, MD, 2002.

surface of the illuminated object. Five hundred lux (about 46 footcandles) of light from a tungsten source (94% IR) will raise the temperature of a surface 2° or 3°C depending on the surface color.[6] The surface expands relative to the body of the object. This differential expansion produces great stress on the object.

Eventually, the interior of the object warms by conduction. The object stabilizes at a new temperature where the thermal radiation from all sides equals the incoming radiation from the lighting. The interior has now expanded to match the exterior.

Figure 3-1.

Porcelain figurine doll damaged by repeated thermal cycles of expansion and contraction.

For fragile artifacts, this should be seen as reversing, rather than eliminating the stresses. Any movement or structural damage caused by the initial expansion of the surface is now repeated as the interior continues to move in relationship to the surface. The fact that the movement is in the same direction only eliminates stress that has not yet resulted in structural damage.

The thermal cycle is not over. The day ends, and knowing the danger of photochemical damage (we have only so many footcandle-hours of exhibit life), we follow accepted conservation guidelines and turn the lights off.[7] Now the surface begins to cool in relationship to the interior of the object, again inducing stress

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[6] Garry Thomson, p. 46.

[7] "Turn off lights during non-public hours so as not to expose objects to light unnecessarily." Toby Raphael, B:6. P. 1.

and structural damage, this time due to differential contraction rather than expansion. Finally, the object reaches equilibrium at its nighttime temperature with the interior cooled and contracted to match the surface.

Figure 3-2.

Even mineral exhibits are subject to damage by differential expansion and contraction. This is how God makes sand out of rocks.

The IR energy in the lighting has caused four separate cycles of movement between the surface and subsurface in one 24-hours period. Structure breaks down, mineral exhibits spall and flake, ceramic surfaces crack, and paint surfaces crack and lift. Very sensitive objects like old ivory carvings and small lacquered boxes can simply collapse into dust without ever being touched. On documents, ink, which is dark and more IR absorbent can spall off of the paper.

Garry Thomson uses a detail of a painting to demonstrate the effects of light on the paint medium (Figure 3-1).[8] The drying and cracking shown in this photograph are directly the result of the differential expansion and contraction caused by infrared radiation. If you have ever observed a light halo of dust on a glass shelf surrounding a mineral exhibit, it is caused by surface spalling from these light-induced thermal cycles. This is how God makes sand out of rocks. We repeat it every day in our museum environments.

Figure 3-3.

Detail of painting showing damage from IR driven expansion and contraction.

3-5 Case Breathing

The second process involves the same radiant energy from conventional lighting and roughly the same cycles of expansion and contraction. This time it is the air inside a case. Radiant energy heats the case and the objects in the case. It also heats the air inside the case. The air gets warmer and expands. As the air expands, it slightly increases pressure in the case and the air leaks into the surrounding gallery.

Later, when the lights and the radiant energy are turned off, the air contracts and the case inhales. This will draw all of the pollutants present in the gallery space into the interior of the case. We will consider the sources and the effects of these pollutants later. What is important here is that this thermally driven case breathing results in the continual pollution of the case interior. Normally, if a pollutant is in the gallery, you will find it inside the cases themselves.

Garry Thomson expects a normal case “with a well fitting lid and no warps or cracks” to replace its volume several times a day.[9] Barbara Appelbaum states

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[8] Garry Thomson, p. 14.

[9] Garry Thomson, p. 107.

that “tightly-sealed exhibition cases can be expected to allow one air exchange a day.”[10] Toby Raphael gives us a chart:

Unsealed cases - 1 air exchange per hour
Moderately-sealed cases - 1 air exchange every 24-36 hours
Well-sealed cases - 1 air exchange every 72 hours
Hermetically-sealed cases - No air exchange[11]

We will look at the possibility of sealing cases later on, but for the moment as air will leak through a .00004” (10 micron) hole, let us see if we can more closely define terms like “well fitting,” “moderately-sealed” and “tightly-sealed.” Defining seals by how well they leak may be fine for evaluating existing cases, but it hardly provides the information necessary for planning or building a case.

It turns out that we can predict the amount of breathing driven by thermal expansion mathematically. First, we need to know:

> “the coefficient of volume expansion for a gas under constant pressure is nearly the same for all gasses and temperatures and is equal to 0.00367 for 1°C.”[12]

As we can expect our “well-sealed” case to exchange air with the gallery, we can make our calculations based upon a constant pressure within the case. (Air will leak rather than build pressure.)

To express the answer in degrees Fahrenheit we will also need to know that 1°F = 0.556°C. The coefficient of volume of expansion of air then becomes 0.00367 x .556 or 0.002 or 2/10ths of a percent per degree Fahrenheit. The coefficient of volume expansion of the air in a museum case is then .002 for 1°F or a 1% change in volume for every 5° F change in temperature.

To put this into practical application, think back to the library case we lit with fiber optic lighting with absolutely no IR. It buffered a 6°F total gallery HVAC cycle to a 2°F total variation inside the case. Our new coefficient of expansion tells us the volume in the case will change 0.4% with each cycle. If you estimate that the HVAC cycles 4 times an hour, 24 hours a day; the case will cycle 38% of its air each day or roughly its entire volume in 3 days. Toby Raphael was right!

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[10] Barbara Appelbaum, Guide to Environmental Protection of Collections, (Madison, Connecticut: Sound View Press, 1991), p. 43.

[11] Toby Raphael, 3:1, p. 1.

[12] The Handbook of Chemistry and Physics, 48th ed., ed. Robert C. Weast and Samuel M. Shelby (Cleveland, Ohio: The Chemical Rubber Company, 1967), p. F-90.

One purpose of this exercise is to define “well-sealed.” We can define “well-sealed” then as no holes, cracks or gaps, that is, completely-sealed, but with no provisions to hold pressure. For practical purposes a case is either sealed or it is not sealed. Sealed cases can be sealed against random air movements or sealed against pressure.

Because of the radical differences in the conditions that drive differential pressures in museum cases, it is not practical to classify case sealing by air exchange. The same case with the same seals will have very different performance under different lighting sources and different air conditioning cycles. It is also near impossible to specify manufacturing specifications or to test for a builder’s compliance with these inaccurate descriptions.

But, it is quite possible to specify and test for leaks in case seals. Ultrasonic testing equipment will show gaps or holes in seals that will allow random air exchange. It is also possible to specify and test case seals for given pressures. For accuracy cases should therefore be classified as unsealed, normally-sealed and hermetically-sealed:

Unsealed - Allow air movement without pressure differential
Normally-sealed – Allow air movement only under pressure
Hermetically-sealed – Allow no air movement

The basic approaches to controlling thermally driven case air exchange in use today involve attempts to seal the case against the pressure differentials or to filter the air as it enters and leaves the case. It seems at this point however that the first step should be eliminating the heat sources that drive case breathing.[13]

3-6 Convection Cycles

A large number of chemical and particulate pollutants common to the museum environment are dangerous to collections. They come from outside the building, from inside the gallery, from visitors and even from the artifacts themselves. We will examine these pollutants and their sources in some detail later in this book. Here we want to consider the way heat sources move air within the gallery and the consequences of this air movement.

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[13] Barometric pressure changes also drive case air exchange. They will be considered in the section on the NoUVIR AIR-SAFE™ where we will propose a third alternative to controlling case air exchange, using an internal pressure compensation device. We will also consider the pollution dangers of hermetically sealing cases.

Pollutants present in museum environments are both gaseous and particulate. Particulate materials above one micron will tend to settle out of still air. Smaller particulates will not. Air currents from air conditioning, visitor movement and the convection cycles can keep dust and materials up to one hundred times that size in suspension.

In nature sunlight drives convection cycles by warming the air. As the air warms, its relative humidity drops and it absorbs water from the surroundings seeking equilibrium. This warm air also rises. As it rises it cools. When the air cools to its dew point the water condenses (usually around particles of dust or pollution), forms a cloud and then falls to the ground. The cooled air also falls and the cycle begins again.

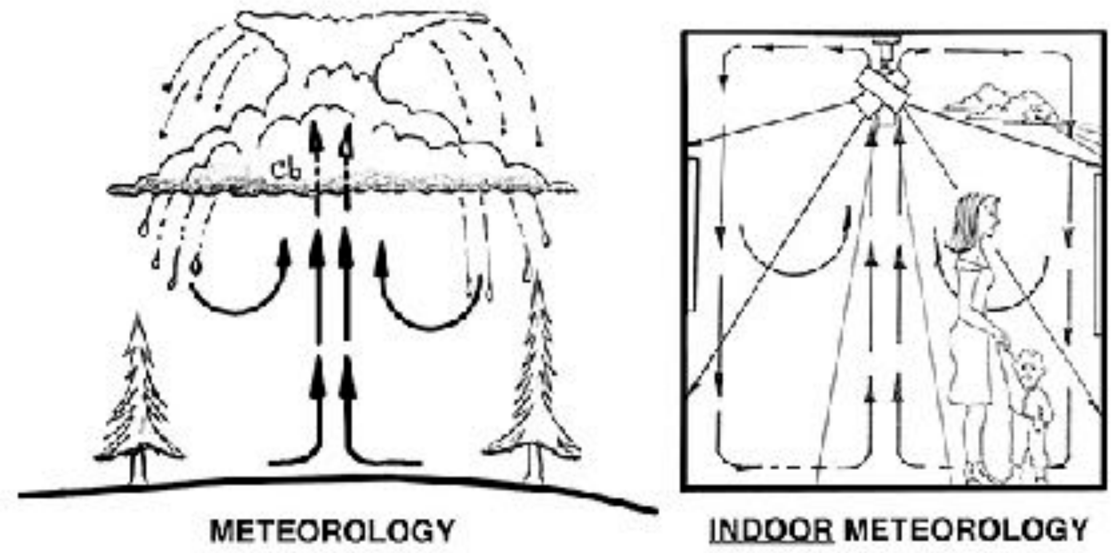

Figure 3-4. Convection “weather” cycles inside buildings.

We have very similar cycles occurring inside of our buildings. The convection cycles here operate between heat sources (usually lighting) and cooler areas (windows and outer walls). Figure 3-4 shows the cycle of air movement across a floor to areas heated by IR radiation and then past the lights and down the cooler walls of a gallery. For a truly horrifying picture consider the floor contents of the vacuum cleaner bag from your organization gently wafting across the surfaces of the painting on your walls.

3-6 Brownian Motion and Thermophoresis

The last temperature driven cycle that creates danger for museum collections is Brownian motion. Brownian motion is the random movement of individual molecules within a particular material. To be entirely accurate it is "a continuous agitation of particles in a colloidal solution caused by unbalanced impacts with molecules of the surrounding medium."[14] At any temperature above absolute zero, the molecules of a solution (air as an example) are continually agitated by random impacts with the surrounding molecules. Picture the ping pong ball machine at a bingo game. The greater the temperature, the greater the agitation and the more violent the impacts. This is, by the way, the reason that temperature and chemical reaction are related.

The application to museum artifacts and temperature is this. Air is a solution. Suspended in air you will find everything from acid gas molecules and micro-particulate carbon to what are in microscopic terms, fairly large chunks of dirt. The greater the temperature, the greater the agitation of the air molecules against these pollutants and the greater they in turn will impact surfaces. The greater the impact of these pollutants with a surface, the more deeply they penetrate this surface and the more likely they are to remain there. The Getty Institute has determined that such particles once they become lodged in a surface are quite likely to be impossible to remove.[15]

Because Brownian motion is temperature driven, air directly adjacent to surfaces heated by IR radiation will have the greatest agitation. And these surfaces will be impacted the most often and the most violently by any pollutants suspended in that air.

Temperature determines not only the velocity and frequency of a surface's impact by air-born pollutants; it also determines the direction that these pollutants move. In an area of temperature gradient, particles suspended in air will be struck by surrounding molecules most often and most violently on the side toward the highest temperature. They will tend to move toward the area that is cooler. This process is called thermophoresis. Basically, in the museum environment it means that warm objects will dry out faster and loose materials (outgas) as molecules are driven away from a surface and cool objects will get dirty faster. Again, the solution is to minimize temperature differentials.

3-8 Temperature Controls

Ideally a museum will want to maintain the lowest temperature possible, but still consistent with visitor comfort. Depending on climate, location, and equipment (especially in historical buildings); this ideal temperature may not be

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[14] The Handbook of Chemistry and Physics, p. F-63.

[15] William W. Nazaroff et al., Airborne Particles in Museums, Research in Conservation (Los Angeles: The Getty Conservation Institute, 1993), p. 7.

possible. It is important to choose a temperature that it is possible to maintain as a constant. Because of the stresses of thermal change, constant temperature may be even more important than absolute temperature.

It is easy to separate artifacts from thermal sources and thermal cycles. A case enclosure is the primary defense against thermal cycles. As discussed above, the use of case enclosures that do not include heat sources can buffer artifact temperature cycles to 33% of gallery changes. Ideally you want to light cases internally with completely IR free lighting. If you must use conventional light sources, they must be kept outside the case and you should use glazing materials that do not transmit IR. (Not glass!)

A case itself can be isolated from temperature driven humidity variations, breathing cycles, pollution and infestation easily and quite inexpensively. Those small temperature variations caused by HVAC cycles and the thermal radiation of visitors can be used to power a highly efficient air filtration system. This will be covered in the sections on case construction and the AIR-SAFE™ system.

Using efficient lighting with absolutely no UV or IR eliminate each of the other problems described in this section. Such lighting has been available from NoUVIR Research for 10 years. This technology and the science behind it have quite literally changed the field of museum and conservation lighting.

3-9 Temperature Summary

Heat cycles increase the rate of chemical reaction, create stress in objects by differential heating and create air movement that drives case breathing and pollution in a museum gallery. Case breathing can be quantified and must be taken into account when considering conservation efforts. Effective museum conservation requires the minimization of temperature differentials in materials, cases and galleries. This is most easily accomplished by the elimination of IR in the light sources. Cases are a primary buffer against temperature cycles. They can be easily isolated to create protected environments for artifacts. You must however control IR in exhibit spaces.