Active and Passive Microclimate Generation

Perhaps there is a museum, someplace, where visitors can be trusted not to touch the objects on display, where the humidity is always stable, and the temperature is forever comfortable. With no dust or pollutants in the air, artifacts can be left naked to the elements, and conservators fret only over the occasional accident or new acquisition.

The rest of us, who must work in less ideal conditions, usually resort to some sort of physical protection for objects on display. The simplest protective space is merely a roof; add some glass to thwart inquisitive fingers, and you have a display case. Now you have protected your objects from hands and falling dust, but you must still deal with those less corporeal culprits: light, pollution, and moisture.

Although designers, engineers and building managers strive for the right combination of illumination, temperature, and humidity, the stark reality is that ambient gallery conditions are often not ideal, no matter how much time, effort, and investment is thrown into the mix. Climate in a gallery may be made hospitable to visitors with some ease, but the conditions demanded by conservators are often much harder to attain.

In the last few years attention has dramatically shifted to the display case as a device for creating and maintaining a safe internal environment- often one that differs from the surrounding ambient air in temperature, humidity, or gaseous content- in short a microclimate.

At the Bottom of It All is Moisture

Almost all organic (and many inorganic) materials in museum collections are composed of microscopic cells or fine structures. Whether dead or alive, these tiny spaces all contain water, and their exact moisture content is very important to their behavior. Most of us know that too much humidity will promote corrosion or other chemical change, or encourage the growth of new life to feed on old (mold, etc.). Small changes in water content can also create mechanical stresses in the object. These can be just as dangerous as destruction by an outside agent, and will vary with the frequency, size and duration of changes in humidity levels.

Controlling Humidity

From a mechanical point of view, temperature control is relatively easy, however, changes in air temperature introduce another variable: any change in temperature affects the air's ability to hold water vapor. As a consequence, while the ***absolute moisture content*** of a mass of air may stay the same (the amount of water vapor contained in the air neither increases nor decreases), the ***saturation*** level of the air varies with temperature.

When air cools it can hold less moisture; if the air cools far enough, the moisture will condense as fog or dew (think of your breath on a winter's day). The opposite is true as well: when heated, the air's ability to hold moisture increases (hot desert air will easily absorb any water it contacts). The air's moisture content at any particular temperature may be expressed as its Relative Humidity (RH). RH is a way of expressing how much water air ***does*** hold, compared to of how much water it ***can*** hold, at any given temperature.

How does this affect display cases? As an example, let's assume a well sealed case contains air at 55% RH, and is sitting in a gallery at 72 degrees. If the case air temperature falls to 60 degrees, the cooled air in the case will be able to hold less moisture, but as the case is sealed, the water vapor has nowhere to go. The water vapor remains in the air, and although no new moisture was added, the RH of the trapped air will now rise to 83%. This level of humidity may be dangerous.

Changes in temperature alone usually present little danger themselves, as the stresses generated are small. However, as we see above, changes in temperature usually result in changes in moisture levels, and the resulting mechanical stresses can be quite severe. Unless some method is used to compensate for temperature driven changes in humidity, RH levels will fluctuate. A stable environment can be maintained by adding and removing just the right amount of moisture from the air.

Microclimates in Cases

Controlling the climate in a museum gallery may be difficult, expensive or impossible. The simplest solution for compensating for uncontrollable variations in gallery temperature and humidity levels is to closely control the humidity in the air immediately surrounding the objects: the case microclimate.

Our first challenge then, is to create and contain a case microclimate that can be modified and maintained. Clearly, the most obvious approach is to design the display case to limit air transfer. This is done by using moisture impermeable materials, and by designing tightly sealed joints and access ports that inhibit air transfer to, and from, the larger environment. Case construction materials must not themselves pose a danger from off-gassed pollutants. Joints and seals must remain stable and not shift or change leakage characteristics with time.

The recent trend in constructing and modifying microclimate cases have aimed towards virtually air-tight sealing. Although these extremely well sealed display cases provide substantially better isolation, they may create other problems such as air stratification, the trapping of gasses released by artifacts or the case itself, or the concentration of radiated heat (greenhouse effect).

Recent studies in indoor air pollution have found that although a tightly sealed case can effectively protect the contents from industrially generated pollution, alarmingly high levels of off-gassed pollutants may be evident in the cases. These dangerous gases (primarily acetic acid and formic acid) are usually a by-product of degeneration of either case construction materials, or sometimes from the objects themselves!

The trapping of radiant heat, and its related effects, may be an especial problem for cases using large areas of acrylic sheeting, which has an insulating value five times that of glass. Remember that changes in air temperature result in changes in RH. A six degree Fahrenheit change in temperature (from 70 degrees to 76 degrees) will result in a seven percent change in RH. This problem should not be overlooked in cases subject to large fluxes of radiant energy throughout the day. Both passive and active systems microclimate control systems will be challenged to cope with this kind of variation.

Active and Passive Controls

Once the atmosphere in a display case is effectively isolated, it can be modified. Occasionally the gas content and temperature are controlled, but generally the most critical and common concern is the maintenance of stable humidity levels. This is usually accomplished using either “active” or “passive” humidity controls.

The distinction is between active and passive control is somewhat arbitrary, as some active systems use the same components as passive systems. To add to the confusion, building engineers may refer to passive building climate control, which will still use fans or other active components. Some have argued that the reactions in silica gel, zeolites, activated charcoal or other materials are chemically or microscopically "active"; after all, at some point, energy was applied to create the conditions needed for absorption, desorption or adsorption of water molecules. It can all get quite confusing.

All that said, the differences between active and passive can be simply put: Passive systems generally refer to arrangements that do not have any electrical power demands; a passive system generally does not need an outside source of energy to proceed. Active systems almost always use fans or pumps to move air within, to, or from the system's components; an external energy source must be used. Active humidity control can be dramatically more efficient than passive methods- think of a sponge compared to a pump, or a lodestone compared to an electro-magnet.

Passive Humidity Control Systems

Consider a sealed box containing an object. Both the object and the air contain water. If the moisture level of the air in the case differs from the moisture level of the object, the object and air will trade water until some equilibrium is reached. This is a simplified explanation of a complex process, but the result is that the object will either give up, or take on water, depending on both the initial differences in moisture content, and the amount of moisture available.

Cloth, wood, and most organic objects often hold sufficient moisture themselves to mitigate humidity changes in a small volume or a crowded display case, but this is only true in certain situations. This ability to self-mitigate moisture changes in the surrounding air will eventually be overpowered by the sheer volume of the air in the case. Even if an object had a moisture content adequate to safely modify the case air, the case leakage (case leakage rates of more than one air change each day are common) would overwhelm any object's ability to modify the surrounding air on its own.

Passive microclimate control systems generally use some sort of "moisture mass" medium that will buffer changes in case humidity. An effective moisture mass holds a great deal of water relative to its own mass, and absorbs and gives it up freely. Silica gel is commonly used for this purpose, and it can be a very powerful tool for maintaining and mitigating moisture changes. Given an adequately sealed case, and enough silica gel, passive microclimate control can be an excellent means of controlling humidity variations in a case.

An accurate estimation of case leakage, a properly sized mass of silica gel, an adequate maintenance schedule, and the means for easily accessing, reconditioning, and replacing materials are all important when designing a passive system. Too small an amount of silica gel, or too high a case leakage will deplete the gel's capacity fairly quickly, and regular replacement of the materials becomes a concern. Recent data suggests that some media can easily absorb and desorb acidic compounds, so proper conditioning routines should be followed when off gassing is suspected.

Active Humidity Control Systems

Active microclimate control almost always involves the mechanical supply of air to maintain the desired humidity limits in an enclosed space. Most systems use fans or pumps to move air to and from the treatment device, which may contain refrigeration compressors, steam generators, desiccant dryers, heaters, misters, bubblers, dampers, valves, gas filters, and mechanical or electronic controls. Microclimate controllers can be in, below, beside, or hundreds of feet away from the case.

In most active microclimate systems, air is passed through a device, usually referred to as a microclimate generator. The mechanics of different generators may vary widely: Air may be dried by using preconditioned silica gel, other absorbent media, or cooled surfaces (that condense the excess water out of the air). Humidification may be added by blowing the air over wet media, past misting devices, or through steam generators.

A mechanical or electronic moisture sensor usually controls the unit's operation. Electronic humidity sensors inside the unit, the case, or in the gallery allow the generator to respond to environmental changes. The more sophisticated units are sensitive to both moisture and temperature.

Two different operating paradigms are usually used; recirculating microclimate generators recycle some or all of the air from the cases, slightly modifying the air with each pass; this allows for the most effective use of the generator's capacity. Constant volume generators inject quantities of air at high or low moisture levels to adjust general case humidity as needed. If the generator is of somewhat limited capacity, the case(s) treated must be very well sealed, and the units ability to rapidly adjust humidity levels may be compromised. Constant internal pressure will help protect objects from pollutant ingress through case leaks, and the larger capacity constant volume generators can inject a constant stream of controlled humidity air in quantities great enough to purge many cases simultaneously, or to feed quite leaky cases.

While humidification in different machines is generally similar, a wide variety of dehumidification strategies are used by microclimate manufacturers, the simplest being blowing air past a drying medium (such as a bag of preconditioned silica gel). While there may be some advantage to non-mechanical dehumidification, this is the most limited system, needing careful monitoring and regular media replacement. When very large volumes of air are used, commercial desiccant "wheels" may be used (as in one early design of a constant volume generator). In this system air is blown through a bed of desiccant as it slowly rotates through a chamber, and the moisture in the air is adsorbed onto the wheel. The moistened material on the wheel then rotates into another chamber, where it is dried by a flow of heated air.

Moisture may also be condensed by directing the air flow over cold plates, cooled with a compressed gas refrigeration system (Freon), or electronically (Peltier cells). Compressed gas systems must be very carefully designed to work optimally, and are generally only used in large coolers or room air conditioning; their large capacity and thermal mass makes them difficult to use to control fine changes in RH. While electronically cooled plates are much easier to control, Peltier Cells are notoriously inefficient, and the capacity of microclimate generators using them is somewhat limited. They are however compact, quiet, and reliable (with no moving parts).

Very small machines may work by first humidifying a flow of air, then drying it appropriately using electronic cooling plates. An RH sensor in the case controls the operation. A Dew Point Relativity (DPR) unit takes this a step further, and offers both humidification and dehumidification effected by a single device. (The dew point is the temperature at which water begins to condense out of the air. The dew point can be calculated for any combination of temperature and humidity.) DPR technology is similar to the laboratory systems used to calibrate humidity sensors, and can be very accurate as well as remarkably stable.

A Dew Point Relativity microclimate system must be supplied with data describing both the current ambient gallery temperature, as well as the desired RH. The on board electronics will then determine the theoretical dew point temperature for the target air RH, and an air stream will be cooled to this temperature. The cooled air stream is then humidified to its maximum holding capacity (its dew point) before being reheated to the ambient temperature. As the temperature of the supply air stream rises, the RH will fall. When the air reaches ambient gallery air temperature, the RH will be exactly as programmed into the unit. This system needs no dampers, nor any evaporative or dehumidifying media, making it extremely reliable and virtually maintenance free.

A Comparison of Active and Passive systems

Passive systems are a simple and effective way to moderate or stop humidity changes in reasonably well-sealed cases. They do not need power, and properly maintained, the media can last indefinitely. They are limited by the transfer of moisture and gases to and from the moderating materials, the quality of sealing of the case, and by the mass of water that the media can effectively hold. As case dimensions increase linearly, the volume increases as the product of the cube. So if a 1 X 1 X 1 meter case leaking at one air change per day (ACD) needs 20 kg of silica gel, a 2 X 2 X 2 meter case will need 160 kg! Case leakage testing is recommended to determine the amount of media needed, as cases can be made with leakage rates lower than one ACD.

Active systems are more efficient at transferring moisture, as even the tiniest CPU cooling fan can move many hundreds of cubic feet of air every day! Even a small microclimate generator can effectively modify a very large volume of air, especially if the case is well sealed. Depending on machine capacity and leakage rates, active systems may be used to maintain a single small case, an entire diorama, or many cases throughout a gallery. With larger capacity units, older cases can often be used with no modifications needed. Most active systems are now designed for a very long, trouble-free life, but are only as reliable as the power supply. Self-buffering by the objects in a moderately sealed case will provide a reasonable level of protection in case of active system failure, and the inclusion of a passive media can also be used where extreme conditions merit extreme safety.

Active systems using positive pressure air supply offer other benefits: Air flow out of the case will prevent dust infiltration, and remove built up heat and off-gassing. Both positive pressure and recycling systems will prevent air stratification. A very small tube into the case is all that is needed to regulate humidity in a well-sealed case. Note that all active systems need some external connection (a source of power, or a hose connection), although battery or solar cell operation may be possible.

Although a microclimate generator can be used to treat a case volume of less than its maximum capacity, active microclimate generation may not be cost effective at very small volumes. While the costs of using passive systems remain constant for each case to be treated (initial costs for silica gel and extraordinary case sealing, as well as regular maintenance), the cost of using a microclimate generation system (initial cost of generator and installation) falls with each added case until the capacity of the microclimate generator is fully utilized. When a larger volume of air (in one or many cases) is to be maintained by using microclimate controls, the overall cost of active microclimate generation becomes very attractive. An active system may provide further savings on case construction and design as extremely well-sealed cases are usually not needed.

Both active and passive microclimate control systems will provide savings in maintenance and cleaning of the objects on display. Either system can provide substantial capital and operating cost savings on general environmental control. In some buildings, the operating costs of providing adequate climate control may seem a trifling in comparison to the costs of designing or retrofitting building envelopes. (Humidity and temperature differentials between inside and outside the building walls can be the cause of severe problems, especially in older structures.)

The extra effort needed to design and create a suitable case, and to provide appropriate microclimate control will pay off in long-term dividends for the institution, and extend the life of the objects. Although a perfect environment, suitable for both visitors and objects, may be hard or even impossible to attain, an optimal situation for artifacts on display is within your reach.

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