Inside the Black Box

An adaptation of a Power Point presentation given by Jerry Shiner of Microclimate Technologies International at the Science of Museum Galleries meeting at the British Museum, London, February 2005

This presentation introduces the basic mechanisms, operating principles, and some varying approaches towards controlling humidity with active microclimate control devices.

Basic Mechanisms

Almost all microclimate control devices contain a humidifying mechanism, a dehumidifying mechanism, some mechanism to transfer air from the device to the case (and sometimes back again), as well as a control mechanism that senses and controls the case RH, provides information to the operator, and ensures the safety of the artefacts within the enclosure.

Humidifying and Dehumidifying

Humidifying mechanisms in microclimate control devices may be quite active (for example, water sprays or steam generators), or almost passive (for example: fan assisted evaporation). In most smaller microclimate units, evaporation is often augmented by using air currents, a bubbler, or gentle heat.

While mechanically adding water to the air is simple, dehumidifying the air is not. A variety of mechanisms exist for removing water vapour from the air, but most microclimate devices use either desiccants or condensation plates.

When using desiccants, such as Silica Gel, the air may be dried by passing over trays or cloth bags (which must be manually regenerated), forced through rigid box filters or cartridges (which are usually regenerated with heat), or blown through rotating wheels (which are constantly regenerated as the wheel passes the different positions of its carriage). Desiccants are generally only seen in devices that must provide dry air only.

Condensation plates, where air is passed over cold surfaces to condense the moisture are common in most microclimate control devices. In larger units, the cold surfaces are usually cooled by compressed Freon systems. These systems and are fairly energy efficient, relatively inexpensive, usually audible, and relatively large (they must have at least a compressor, a radiator, and fan). It is important to note that compressors are either turned on or off, and offer very little variability in output- they are essentially binary in operation. This can present difficulties when attempting to use compressor cooled plates for microclimate applications.

Condensation plates can also be cooled using thermoelectric cooling devices (usually referred to as "**Peltier Cells**"; see addendum below for a more detailed explanation). These electronic devices are relatively energy inefficient, and when judged on total heat transfer capacity vs purchase price, are fairly expensive, too. However, they are silent, extremely compact, and unlike compressor systems they can (when properly controlled) provide a continuously variable output.

Moving the Air

Given that all this transferring of humidity occurs inside the Black Box, the moisture-modified air must then be transferred by some mechanism to (and sometimes from) the treated enclosure. The air transfer mechanism may consist of one or more fans, or occasionally, pumps.

Fans, in general, offer high volume flows at low air pressure. Noise levels vary dramatically, but in most cases, low level fan noise is not particularly objectionable. Fans use a very simple mechanism (a wheel rotating upon a shaft), offer an easily variable output, and are readily available in a wide variety of designs and capacities.

Pumps, in general, offer low volume air flow at high air pressures. They are generally more audible, generating a more "mechanical" sounding noise. Pump mechanisms are more complex than fans, involving valves and reciprocating diaphragms or pistons. A pump's output can be choked back, but the output is not as easily varied as a fans. Lastly, the selection of ready-made pumps is limited.

Controlling the Output

A control mechanism must be used not only to direct the other components to create the desired microclimate, but also to ensure the safety of the objects (providing data, alarms, failsafe systems, etc.). While mechanical controls still exist, currently available units use electronic devices. The control mechanism can be assembled from either ready-made components, or it can be custom designed and produced especially for the microclimate control device.

Off-the-shelf electronic controls are readily available, as they are used in many industrial applications; many are cheap & cheerful. However, as these controls are designed to be inexpensive and are designed for fairly specific industrial uses, modifications in function. and range of operation are usually quite limited. Sophisticated electronic controls are available, but devices with wide ranging capabilities come at a much higher price.

Custom-made electronic controls can give a microclimate manufacturer exactly what they need, but creating a custom board is labour intensive and expensive. Development and manufacturing can also prove costly. However, this kind of investment has its benefits: a custom-made control system can be designed to do all the operations necessary, and they can be modified and improved with experience.

Operating Principles

Given the constituent mechanisms outlined above, how do they function together to provide a safe environment for an artefact? There are a number of ways that we can make the device operate. Before we design an appropriate active microclimate solution to our application, we need to know more about what is needed.

A good analogy is the exercise you must go through when choosing a car. You must consider a number of variables, such as capacity (expected passengers, luggage, tools, materials, etc.), ambient conditions (weather, roads, availability of fuels), maintenance, safety, depreciation, cost, control systems, extra features wanted…

When designing, or choosing a Black Box for humidity control, you have the same basic concerns: what capacity will you need? (how big is the case, how leaky?), what ambient conditions can you expect to find surrounding the case? (does the gallery temperature vary? how?), then there's maintenance, safety, depreciation, cost, control systems, extra features…

As a consequence, when choosing an appropriate humidity control device, it will help to know, or estimate the following:

- How leaky is the case? How leaky might it become in the foreseeable future? (Shifting alignment and damaged seals can dramatically change leakage characteristics!)
- How many cases will be on the system? How are they laid out?
- How extreme, and how rapid will any temperature variations be? Changes in temperature will cause changes in Relative Humidity even when no air enters or leaves the case.
- Will you need pollution control?
- How quickly will you need a case to return to set values after opening?

The most fundamental, and important choice a microclimate designer must make is the method of delivery of humidity to the case. How will they combine humidification, dehumidification, air movement and control. I call this the "Delivery Paradigm", and it is of great importance to the operating capacity, effectiveness, and safety of the unit.

Delivery systems can be described as either binary or modulated in operation. That is, they either have on and off functions only, or they can modify their output over a range of values.

Generally, binary microclimate control systems function by the addition of air at humidity or temperature levels that are substantially above or below the desired target level. The designer is limited to either turning on or off the moisture modifying mechanisms within the black box, or starting or stopping the airflow. Air from a binary system microclimate controller must be thoroughly mixed with the air in the case to raise or lower levels to the desired value. This is essentially the approach used in industrial and home Heating Ventilating, and Air Conditioning (HVAC).

The HVAC / binary approach is cheap and cheerful- it needs minimally controlled input and simple controls to function. However, binary systems are always prone to overshooting, a condition where the humidity levels continue to change after the set point has been reached, resulting in a constant cycling above and below the set points. To maintain this cycling within an acceptable range, the delivery rate and a variety of sophisticated controls must be very carefully adjusted. Another problem of intermittent operation is the increased likelihood of stratification.

An alterative system that avoids many of the pitfalls of the HVAC approach utilizes a constant supply of air that has been preconditioned to the desired set point. In this system, sometimes referred to as electronic buffering or displacement microclimate control, air in the case, no matter what the level of humidity or the pollutant load, is constantly displaced by a gentle flow of conditioned air from the microclimate device.

The specialty approach using displacement is more demanding to design and needs an accurate and responsive control system, as the mechanism inside the black box must be constantly accurately modulated and controlled. However, with displacement delivery there is virtually no overshoot, and a well designed airflow at the desired humidity levels prevents and breaks up stratification. (Pollutants from off-gassing may be easily flushed.)

Another advantage of displacement units is their ability to function well in temperature control applications. A fully modulated, displacement system unit can interface seamlessly with a temperature control device, while a binary, HVAC unit will be especially prone to rapid and difficult to control humidity fluctuations.

What's available?

The basic mechanisms and operating principles described above may be combined in a wide variety of microclimate control systems. Generally, they can be divided into large units, intermediate units, and miniature devices.

Large capacity devices are generally kept in a machine room at some distance from the gallery (up to 150 m / 500 feet, or more). They can be used to feed many cases, both large and small in a single gallery, or used for an archive or storage room. These units generally feed a positive pressure air flow to the cases through a system of distribution piping. Unlike conventional systems, they operate on the microclimate displacement mode.

Intermediate capacity devices will feed a few large or small cases, usually from a location near the cases. They may offer positive pressure or recirculating systems, with a wide variety of options for air delivery. Displacement mode units can be used for very small enclosures, such as glazed and sealed picture frames, which would otherwise be prone to overshoot.

Miniature devices can be surprisingly effective while remaining very compact, and are generally located inside, or very close to the vitrines to be treated. They are usually used as one device for each case, and can be either positive pressure of recirculating feed.

Although the science of the mechanisms used to create a microclimate control device is relatively simple, the art of combining them is not. Much of the work involved in designing and building a system is trial and error, and "inspired guesswork" plays an equal role to engineering.

As the end user of an active microclimate control system, a general understanding of the different mechanisms and delivery paradigms will help you to select and utilize your system to provide the safest, most accurate climate control.

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Addendum:

Thermo Electric Cooling:

Peltier Cells are named after Jean Peltier, who discovered the thermoelectric cooling effect in 1834.

The principle behind thermoelectric devices was first discovered in 1821 by Thomas Seebeck. He observed that if a closed circuit was made from two dissimilar metals, an electric current flowed when the junctions were maintained at different temperatures. The reverse of this – application of a DC voltage to a closed circuit comprising dissimilar metals gives rise to a temperature change at the junction of the dissimilar metals. Modern thermoelectric cells use semiconductors, usually Bismuth Telluride.

As a current passes from one side of a Peltier Cell to the other, there is a decrease in temperature at the cold junction, resulting in absorption of heat from the environment, thus creating a cold surface. The heat is carried through the device by electron transport and released on the opposite (hot) side as the electrons move from a high to low energy state. (The junctions are connected electrically in series, and are laid out flat and sandwiched between two ceramic plates.)

In a microclimate control device, heat dissipation plates are attached to both hot and cold plates on the opposite sides of the cell, for effective transportation of the heat to and from the air. Generally, fans must be used to assist in moving the heat energy on both sides of the Peltier Cells.