Thirty Years of Sustainable Control of Relative Humidity

by Dennis Piechota and Jane Drake Piechota

Abstract

The authors review the past three decades of their use of saturated aqueous solution/slurries of magnesium nitrate hexahydrate to maintain microclimates with a midpoint of 54% and an accepted target relative humidity range of +/- 5% (49% to 59%). They describe the properties of magnesium nitrate hexahydrate and give step-by-step instructions in how to safely use it to create stable sustainable environments for humidity sensitive museum collections. They present two case studies as examples of its use in museum display and storage cases housing archaeological wood, bone, textiles, and other organics.

Introduction

Few methods used by conservators go unchanged for decades. We adapt them to meet our evolving values and goals. We pride ourselves on being open to constant self-examination, re-evaluation, and improvement. During our careers we have moved from embracing the goal of reversibility in the 1970s (Keck, S., 1961), redefining it to retreatability in the 90s (Appelbaum, B., 1987), focusing on non-material values in the new century (Clavier, M., 1996), and most recently stressing our role in creating a just, resilient, and sustainable world (AIC, 2024).

Even the word 'sustainable' has evolved. Initially it was a way of asking if a solution is financially sustainable for the institution, e.g., could the energy costs of an air handling system be maintained. Then as we became museum consultants 'sustainable' also meant are the environmental solutions we developed simple and reliable enough to be maintained by the museum staff in our absence. Now as our role in creating human-induced climate change became apparent 'sustainable' also focusses us on furthering climate resilience and social justice.

So in a sense the unchanged method described here, the use of a saturated magnesium nitrate solution for micro-climate control, is an outlier. For decades it has remained largely unchanged. It has new relevance today as we add sustainability to our evolving methods and goals. In that sense it is hard to improve on the concluding statement made thirty-three years ago by Eva Astrup and Kristin Stub in the paper they delivered at the 1990 ICOM meeting in Dresden

> "…the great advantage of the saturated salt solution system for humidity control lies in the fact that it is a cheap system which is easy to set up and free from break-downs, it is independent of electrical supply and little maintenance is needed" (Astrup and Stub, 1990).

Our current apparatus for this method for microclimate relative humidity (RH) control still follows that described by Julie Creahan in the January 1991, Volume 13, Number 1 issue of the WAAC *Newsletter*. The only difference is that Julie used a saturated solution of calcium nitrate, which equilibrates when saturated at 20ºC to approximately 51% RH (Creahan, 1991) and we use a saturated magnesium nitrate hexahydrate which at the same temperature equilibrates at approximately 54% (Greenspan, 1977).

Review

Saturated salt solutions have been used for over a century to create controlled micro-environments for laboratory experiments. In addition to serving as a primary source for the calibration of hygrometers, (Wexler, 1954) they have also been used to study the effect of humidity on food preservation, the growth rate of microorganisms, the performance of electrical and microelectronic components and many other applications (Edgar and Swan, 1922; Ewing, Klinger, and Brandner, 1934; Greenspan, 1977; Richardson and Malthus, 1955; Winston and Bates, 1960; Young, 1967).

When salt is dissolved in water, it reduces the vapor pressure of the resulting solution. The ions from the salt exert an electrostatic hold on water molecules that would otherwise evaporate. This hold increases until saturation is reached, meaning the salt either begins precipitating out as undissolved crystals or it goes into a state of supersaturation.

At that point the vapor pressure becomes fixed, stable, and characteristic of that dissolved mineral. Since the vapor pressure of pure water will vary slightly within ambient air temperatures of 20º to 25ºC (68º to 77ºF) there will be a consequent variation of a few per cent in the stabilized vapor pressure of the dissolved salt.

In closed containers, where vapor pressure can equilibrate with the surrounding air, we commonly measure that fixed vapor pressure through its related value, relative humidity. The saturated salt solution described here, magnesium nitrate hexahydrate, will equilibrate at a relative humidity of 54% at 20º C. Other salts equilibrate to different relative humidities (ASTM, 2020).

Importantly this equilibration process occurs under both dry and damp aerial conditions. While saturated salt solutions will gain and lose water vapor, it should not be assumed that the rate of moisture loss will be equivalent to the rate of gain. However, in the applications described below the permeability of the membrane covering the tub containing the saturated salt solution is the limiting factor that equalizes both the uptake and discharge of water vapor from the tub.

An early museum application of this method used two different salts to define maximum and minimum relative humidities but a single salt can serve as well (Cursiter, 1936).

When the air above the surface of the saturated solution has a high relative humidity, the solution will serve as a desiccant absorbing moisture until it reaches equilibrium at its characteristic relative humidity. It then serves as a humectant if the air above the solution dries. This is critical to applications for the maintenance of constant microclimates in buildings having wide daily or seasonal climate variations.

The chemical compound discussed here, magnesium nitrate hexahydrate, was first encountered as a naturally occurring mineral termed nitro-magnesite. Early mentions of it in 19th-century compendia describe its discovery in caverns and mines under geologically stable conditions (Shepard, 1835).

As well as controlling relative humidity recent research has shown that saturated solutions are also effective at reducing in-case pollution (Eggert, G. 2023).

Defining the Forcing Environment and the Goal

While there is no single ideal relative humidity for all collections, extreme cycles in humidity levels can cause incremental damage to many materials (Buck and Amdur, 1964; Rogers, 1976; Michalski, 1993). Humidity sensitive archaeological organic collections have been our focus. These include ancient Egyptian painted coffins and cartonnage as well as leather, wood, and bone collections from historic sites.

Our experience with this method is within the aerial environment of a northern temperate climate, specifically that of eastern Massachusetts. There the annual outdoor temperature and relative humidity fluctuates broadly. In the summers we experience high temperatures and humidities while the winters are cold and often dry. In response our buildings are typically designed to be heated then cooled following the predictable annual cycle.

To buffer these extremes in display cases and storage cabinets, we have applied the current relative humidity microclimate solution within two types of forcing environments.

Galleries or storage rooms with static air masses in buildings that are heated centrally and often cooled locally. This "Matrushka-like" environment has, instead of nesting Russian dolls, nested static air masses, e.g., a display case in a gallery in a building.

Galleries or storage rooms with dynamic or forced air masses connected through ducting to a building-wide HVAC system.

Poorly controlled humidity in each forcing environment, whether from still or forced air masses, presents differing hazard levels to humidity sensitive collections with the former creating seasonal extremes and the latter potentially daily instability.

To reduce energy and maintenance costs in both types, buildings are commonly heated and cooled for human comfort alone. Extensive justification, budgeting, and retrofitting is needed to upgrade the equipment for the control of relative humidity in addition to temperature.

In the Still Air forcing environment of rooms or galleries with static air masses, local room air conditioners installed for comfort cooling in the summer heat will in the process reduce extremes of high humidity.

Local humidifiers avoid the lowest humidity levels in the winter though the moisture they introduce must be limited in old construction as it can be damaging to the building envelope. Humidity sensitive collections must be protected from the seasonal fluctuations of Still Air environments. (Figure 1).

Forced Air room environments pose a special problem for humidity sensitive collections. To maintain human comfort, moisture is often injected into the ducted air streams of HVAC systems to reduce temperature through evaporative cooling. While this method of temperature control is most efficient when the air is dry, it has been also used year-round leading to wild hourly fluctuations in humidity.

In the winter the humidity has occasionally risen from below 10% up to 80% in a matter of hours. In the summer the uncontrolled building humidity is typically high and can fluctuate from a low of 50% up to 80% depending on outside conditions and evaporative cooling performance.

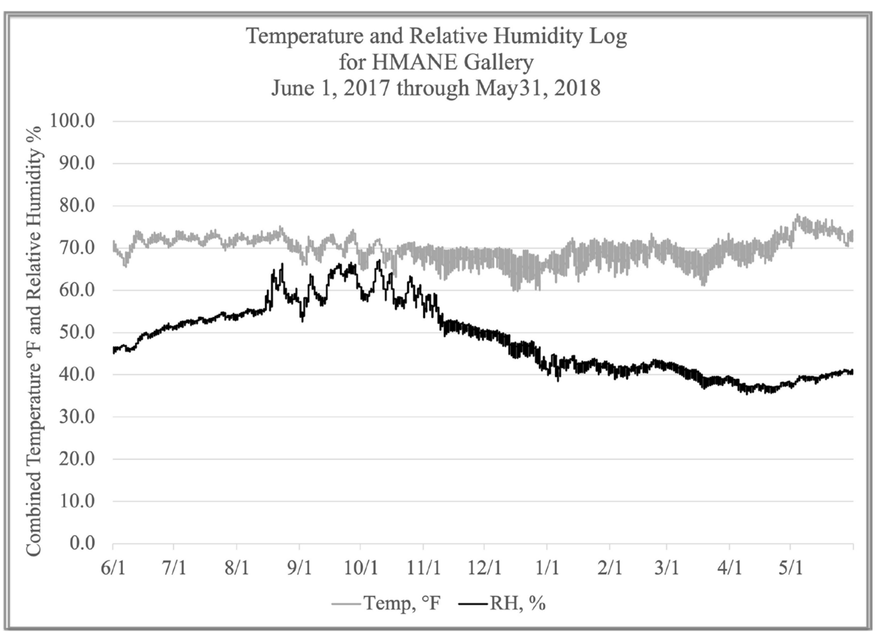


Figure 1. Still Air Environment

A combined temperature and relative humidity log for a second-floor gallery at the Harvard Museum of Ancient Near East (HMANE) showing a primarily seasonal fluctuation in humidity as well as some increased daily instability caused by a window air conditioning unit operating during the summer months. It covers the period from June 1, 2017 to May 31, 2018.

(Source: Onset Hobo Model H14-001 with +/- 3% RH accuracy.)

In buildings without air handling systems the daily relative humidity variation is relatively stable being limited by external conditions.

But annual variation can still result in relative humidities that range from less than 10% when cold unconditioned winter air is heated to room temperature to over 80% during summer rains (Figure 2).

Early in our careers we took spot and short-term readings of the temperature and humidity of the gallery and storage room using dial hygrometers and recording hygrothermographs. Though prone to machine and sampling error these allowed us to begin estimating both the annual average and median relative humidity in the era before dataloggers.

We found that the rooms were more consistently low and more randomly high. The median was 33% while the average was 47%. Both values are below the 54% value that magnesium nitrate hexahydrate will maintain. This means that annually the solution will function more often as a humectant than a desiccant causing a slow loss of moisture as the solution equilibrates to seasonal highs and lows.

In this setting the goal then is to identify collections that may be harmed by such humidity variation and to stabilize their immediate aerial environments. While this can and is done on a building scale, it can be more practical and is certainly more sustainable to identify and isolate sensitive collections within smaller airspaces where control can be accomplished through non-mechanical means.

In cultural institutions this then focusses our attention on creating stable micro-environments for particular material types within exhibit and storage cases.

As we focus on controlling small environments we must consider that the humidity instability will also result from more local effects. It is convenient and useful to group all effects, large and small, outside of the immediate controlled airspace as the forcing conditions that will act upon the range, speed, and frequency of the micro-environment's instability. These will include the temperature of the room, the airtightness of the case, how often it is opened and kept open, its proximity to outside walls and whether external lighting may cause radiant heat of the exhibit case and its contents.

While the external instability of the forcing conditions around existing cases is our primary concern, in new installations we may design and outfit the cases to add humidity moderating conditions. Hygroscopic textiles in exhibit cases and paper-based trays and boxes within storage cases can both provide a fast-acting moisture reserve important in lessening short-term variations.

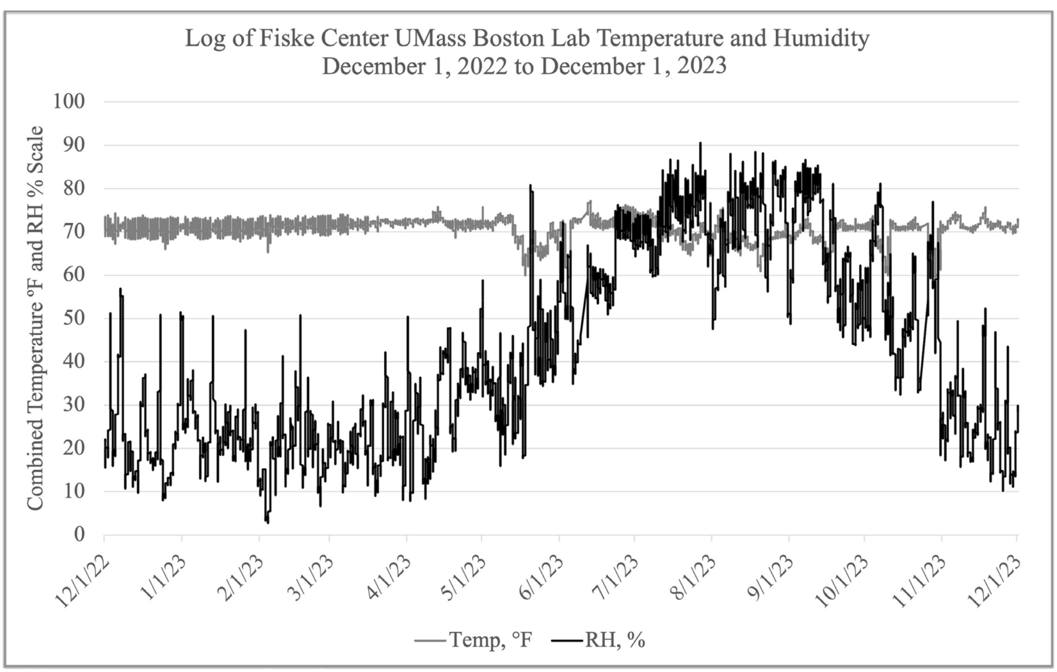
As archaeological conservators we commonly focus on maintaining two stable micro-environments, desiccating for unstable metals (Piechota, 2016) and mid-range for organics. This paper focuses on mid-range humidities, maintained for a wide range of organics from newly excavated fragmentary fabrics to polychromed and jointed Egyptian sarcophagi.

To accomplish this for over twenty years we have used saturated magnesium nitrate hexahydrate solution. It has maintained a midpoint relative humidity of 54% at 20ºC with an acceptable variation from that target of +/-5%.

Unlike the original laboratory applications which used open and unlidded trays for the most efficient and responsive equilibration, museum trays must have vapor permeable lids

Figure 2. Forced Air Environment

The combined temperature and relative humidity log for the room containing the storage cabinet filled with sensitive archaeological organics. Typical of 'comfort cooling' systems, note the tight control of temperature and extreme daily variability in humidity (shown in black) caused by spraying water mists into the ductwork of the HVAC system to control temperature (shown in gray) through evaporative cooling. It covers the period from December 1, 2022 to December 1, 2023. (Source: Onset Hobo Model UX100-011A with +/-2.5% RH accuracy.)



to isolate the liquid from accidental contact with the collections and case hardware.

The vapor permeable container design has remained largely unchanged for over three decades. It started as an adaptation of Julie Creahan's 1991 WAAC article (Creahan, 1991) describing customized commercial plastic tubs to safely isolate the liquid solution from the artifacts in the storage or exhibit case.

While this solved the key problems of accidental spillage and creep, the introduction of a vapor permeable barrier between the controlling solution and the target air space does cause a relative inefficiency in response and control when compared to the use of open trays of saturated salts described in laboratory experiments.

In 1992 the authors conducted a series of tests comparing the water vapor transmission rates without any membrane to that through two different vapor permeable membranes, non-woven Gore-tex and Tyvek Type 10. Following the current ASTM protocol, ASTM E96-22, the gravimetric determination of barrier permeability to water vapor, the weight loss from standard beakers of distilled water was recorded in a controlled desiccating environment of 20% RH and 25ºC.

It was found that for every 100 grams of water lost from the uncovered beaker, 48 grams evolved through the non-woven Gore-tex and 39 grams from the Tyvek Type 10 membranes. These anecdotal findings were useful in focusing our attention on the importance of monitoring the response rate of the proposed tubs in dynamic environments especially if we were to move from using Gore-tex to the less expensive and freely available Tyvek.

This trade-off is only acceptable because, unlike laboratory experimental designs, our goal of humidity stabilization allows for a limited range of variation around the target humidity. We accept a +/-5% range from the target of 54%. The range is determined by the dynamic nature of the surrounding forcing environment, i.e., the room, the frequency of case openings, and the tightness of the case as well as the amount of surface area of the saturated solution.

A Step-by-Step Procedure for Controlling Relative Humidity with Magnesium Nitrate Hexahydrate

1. Get to know the forcing environment surrounding your proposed microclimate by placing temperature and humidity dataloggers in the proposed microclimate case and the surrounding space.

Inexpensive loggers such as Hobo MX1101 by Onset Computer are Bluetooth-enabled allowing access to data without opening the case and have sufficient accuracy (+/-2%). Installing tandem loggers in and out of the case will define the longterm or seasonal variations in your forcing environment and allow you to evaluate the performance of the saturated salt solution.

While one reading per hour will be adequate for annual trend analysis of rooms with still air, multiple readings per hour may be needed to detect short term effects, for example, within rooms with HVAC controlled forced air circulation.

2. Record the dimensions and construction of the proposed microclimate case. Knowing its internal volume will allow you to start estimating its annual water vapor budget and to improve the tightness of the case.

As you maintain the case humidity by annually topping off the salt solution (assuming an overall loss in moisture) you will be able to develop its annual moisture budget. Seasonal re-weighings that separate periods of high and low humidity can be used to estimate the relative air tightness of your micro-climate. Knowing the seasonal gain or loss and assuming that each cubic meter of air at 54% RH and 20ºC contains 9.4 grams of water vapor you can calculate the equivalent air changes per day.

3. Record the floor space available for the tubs of saturated magnesium nitrate. In general the more tubs with saturated solution that can be installed the less maintenance will be required.

4. Select a lidded plastic tub type and size that will fit within your microclimate floor space.

The following method will reference a particular brand of food storage container. While other containers can be selected, the authors have used Rubbermaid-brand food storage containers for decades. The current version has a capacity of 2.5 gallons (9.5 liters) with dimensions of 16.5"L x 11.5"W x 5.6"H (42 cm x 29 cm x 14 cm) and is sold under the trade name "Racer Red" with "Easy Find" lid. The tub is composed of polypropylene with a polyethylene lid. It is identical in construction to the original 2.1 gallon (8 liter) "Servin Saver" that has been safely and continuously used for saturated solution storage since 1991 (Figure 3).

Figure 3. Original and Current Rubbermaid Tubs

On the left is the current 9.5-liter Rubbermaid tub being used to hold the saturated magnesium nitrate hexahydrate. On the right is a 1998 Rubbermaid Servin' Saver tub still in use at the Fiske Center. Both lids have white Tyvek membranes added to the cut-out centers.

Note that when refilling the tubs there is no need to crush the solid magnesium nitrate crystals in the bottom of the tub. In fact this may cause stress to the polypropylene tubs that could over time cause cracking and leakage. A slow rocking of the tubs and reintegration of any the creeping crystals followed by reclosing the lid will lead to quick re-saturation.

Concentrated but not fully saturated magnesium nitrate hexahydrate solutions will still exert partial control over relative humidity. The case humidity will not suddenly increase (Young, 1967).

5. Modify the tub lids to accept the vapor permeable membrane. While this reduces the evaporative surface area and rate of humidity response of the solution it is essential to preventing accidental spillage. It will also retain the inevitable creep of salt crystals up the interior walls during desiccation (Figure 4).

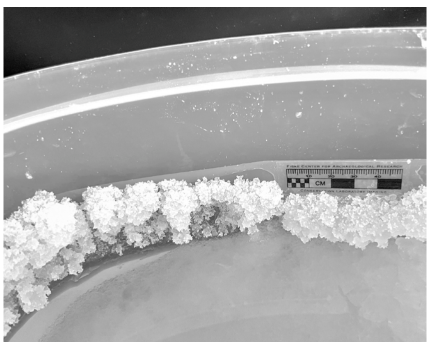


Figure 4. Closeup of Magnesium Nitrate Hexahydrate Crystal on Interior Tub Wall

A close-up image of a tub wall with the lid removed. This shows an example of 'creeping' salt crystals that one typically encounters in tubs that have been exposed to long periods of net desiccating conditions. If the tub fill level is kept to one half or less, the magnesium nitrate hexahydrate crystals remain safely within the tub.

6. Over the years several forms of vapor permeable membrane have been used. Currently we use Tyvek Type 10, a nonwoven polyethylene, adhered with hotmelt glue to the underside of the central area of the cut away lids (Figure 5).

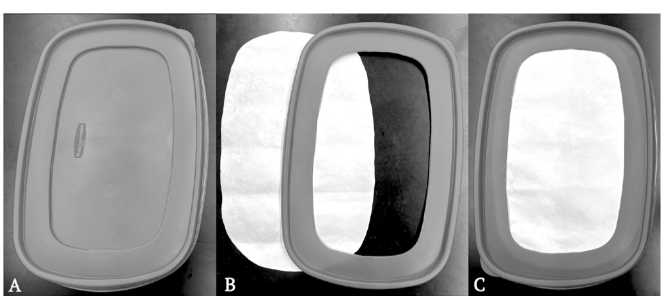


Figure 5. Tub Membrane Sequence

A- Rubbermaid Red Racer 9.5-liter (2.5 gallon) tub lid before center panel is removed. B- Center panel removed from lid and Tyvek Type 10 membrane cut and ready to be adhered to the underside of the lid using hotmelt glue. C- Finished lid with membrane in place.

7. Observing standard laboratory safety procedures, dis solve reagent grade magnesium nitrate hexahydrate in distilled or deionized water at a concentration of two and a quarter to three kilograms per liter. This range is well above the maximum solubility of magnesium nitrate hexahydrate and in temperate climates it allows one to confidently avoid desaturation.

For installations where the forcing environment cycles annually above and below 54% relative humidity, the starting concentration of solute will depend on whether you are currently experiencing a damp or dry period.

If the installation is done when humidity is high, use three kilograms per liter. This high level will be able to absorb the ambient moisture without desaturating the solution. If installing during a dry period of the cycle, one can start with two and a half kilograms per liter.

Note that when mixing two and a half kilograms per liter the solution can be supersaturated and show no undissolved salts. It will still control the humidity as well as solutions showing obvious undissolved salt.

To confirm saturation in the absence of precipitated salt one can use a hydrometer. A density reading of 1.37 gm/cc or above indicates that the supernatant solution is saturated (Figure 6).

	INFREQUENT DAMP PERIODS (minimum recommended salt ratio)	STILL AIR WITH EXTENDED HEATING SEASON	FORCED AIR WITH COMFORT COOLING HVAC SYSTEM
Ratio of Magnesium Hexahydrate to Water (weight to volume)	2.2:1	2.6:1	3:1
Total Solution/Slurry Volume (ml)	4200	4200	4200
Magnesium Nitrate Hexahydrate Weight (gm)	4000	4100	3800
Deionized Water Volume (ml)	1825	1525	1260
Approximate Volume Increase % (over initial water volume)	230	275	300
Density of Supernatant (gm/cc)	1.37	1.38	1.39

Figure 6. Table of Solution Ratios

Table of three forcing environment types with recommended sample quantities and proportions of magnesium nitrate hexahydrate and water used to fill just under half of the rated capacity of a Rubbermaid brand 9.5-liter (2.5 gallon) Red Racer food storage container.

8. Mix the salt and water of each tub. As a mixed solution of both dissolved and undissolved salt it is most accurate to prepare each tub separately. Prepare a spreadsheet recording the initial gross weight of each tub. Presuming a gradual loss of water vapor over time this will be the weight you will refill to during future maintenance cycles. Also for reference include the date of deployment, weight of the salt, the volume of deionized or distilled water, and the final volume of the solution including slurry.

9. Install the tubs with an in-case datalogger and re-weigh them annually. Even if they do not need re-filling, the initial annual weighings allow one to develop that case's net annual moisture budget. That weight is compared to the original gross weight, and typically a small amount of water is added to bring it back up to its original gross tub weight.

Temperate climate winters are on-balance drier and longer than the summers are wet. In our heated buildings the time spent below the mid-range RH is greater than that above, leading to a slow desiccation of the tubs and avoiding de-saturation of the nitrate solution.

The water weight record you create when topping off the tubs gives you a clear record of the net annual moisture budget of each case in milliliters water/air volume/year. This is very useful when designing new cases in general, diagnosing case tightness, and predicting future maintenance needs. For more detailed breakdowns one can add seasonal weighings, for instance at the beginning and end of a heating season.

Two Case Studies

While the authors collaborated on all aspects of writing this article, they would like to note that the first case study was developed by the authors working together as consultants in private practice for the Harvard Museum of the Near East. The second case study was done at the Fiske Center of Archaeological Research where the lead author alone is currently employed.

Included are representative logs of the room air, i.e., the forcing environment and the controlled in-case air. The accompanying bar graphs analyze the logs with respect to the target humidity range of 54% +/-5%. Readings are graphically displayed in four columns, those outside the range, that is, above 49% and below 49% as well as those that are above and below the 54% reading but still within the control range.

Case 1: A Display Case in a Still Air Forcing Environment

A display case containing a 22nd dynasty (945-730 BCE) cartonnage mummy case has had a micro-climate controlled for 18 years using saturated magnesium nitrate hexahydrate.

A hieroglyphic inscription on a papyrus found with the mummy read in part, Pa-di-mut, son of Nes-pa-Sefe-Pa du mut and Auk-es-ast, a worker in metals. His mummy casing is installed in a custom display case on the second floor of the Harvard Museum of Ancient Near East (HMANE), formerly the Harvard Semitic Museum.

The construction of the polychromed cartonnage is as complex as it is fragile. It is a three-dimensional laminate composed of layers of linen and a calcium carbonate ground surfaced with thin paint and resin layers. The soft ground and fabric support showed sensitivity to changes in relative humidity leading to flaking of the thin surface resin and paint (Farrell et. al., 2005). Given the still air forcing environment of the gallery space a stable micro-climate was needed.

In 2005 six 8-liter Rubbermaid Servin' Saver tubs were deployed under a ventilated deck of the case measuring 61 cm x 183 cm x 198 cm (24" x 72" x 78") with a volume of 2.2 cubic meters. Each of the six tubs had 300 milliliters of water available giving a total of 1800 milliliters available for the extended heating season when the magnesium nitrate hexahydrate would function as a humectant (Figutre 7).

Figure 7. Padimut Display Case Showing Tub Locations

The microclimate display case containing the ancient Egyptian cartonnage from the burial of Padimut. The front of the case has been removed to expose the six tubs of magnesium nitrate hexahydrate at the bottom used to passively control the case relative humidity.

Initially our understanding of the forcing environment was guided only by sporadic temperature and humidity readings. But with the micro-climate installation we started maintaining tandem datalogs of both the gallery and internal case spaces. The year from June 1, 2017 to May 31, 2018 is representative of the forcing environment and control case.

Over that period 17520 readings were taken in the gallery, one every thirty minutes, using tandem Hobo dataloggers Model H14-001 by Onset Computers. 66% of the readings fell outside the target range, either above or below the accepted variance of 49% to 59% RH. Fully 53% of all readings were below 49% indicating the importance of controlled humidification (Figure 8).

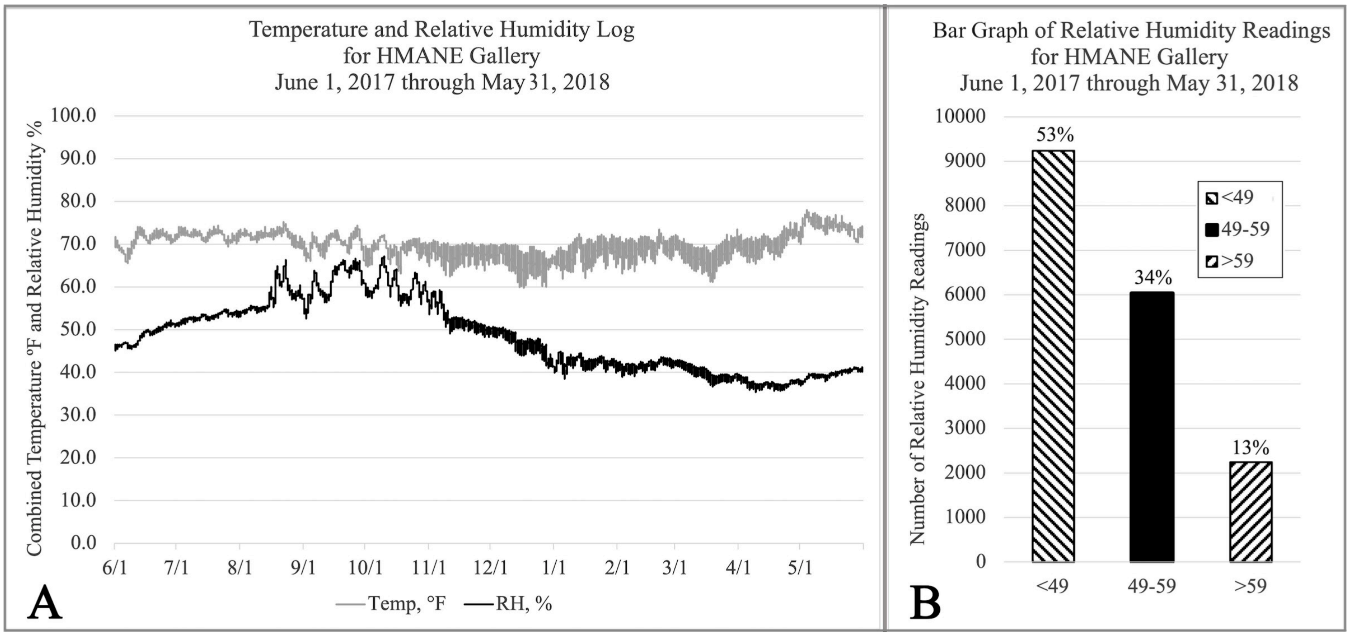


Figure 8. Gallery Air Log and Bar Graph

A - The combined temperature and relative humidity log of 17521 readings taken every 30 minutes from June 2017 through May 2018 for the gallery with the display case containing an ancient Egyptian cartonnage. As an example of a still air forcing environment it shows the extremes and monthly variation in the gallery air surrounding the micro-climate display. (Source: Onset Hobo Model H14-001 with +/-3% RH accuracy.)

B- A bar graph of the relative humidity readings shown in A. Note that only 34% of the readings fell within the target range of 49-59% RH.

At the same time within the magnesium nitrate hexahydrate controlled micro-climate 84% of the readings fell within the accepted range indicating success but also suggesting that ways to make the case more airtight and add more solution would be beneficial.

The average annual net moisture budget of the display case was 1.6 to 1.7 liters per year. Since the original six tubs each had only 300 milliliters of water available for a total of 1.8 liters, they would have come close to dryness if the forcing environment supplied only dry air year-round.

However a significant amount of moisture is replenished during the summer periods when the salts re-absorb excess damp, so the actual total loss, i.e., original tub water plus summer replenish, was greater than the recorded annual weight.

This is useful when using the moisture budget to estimate the draftiness of one's case. For better accuracy a few sample weighings should be done seasonally, separating the damp periods from the dry periods. We did not do that. In fact, as consultants we noted that scheduling conflicts and funding period restrictions interfered with maintaining a regular annual re-weighing schedule. (Figure 9)

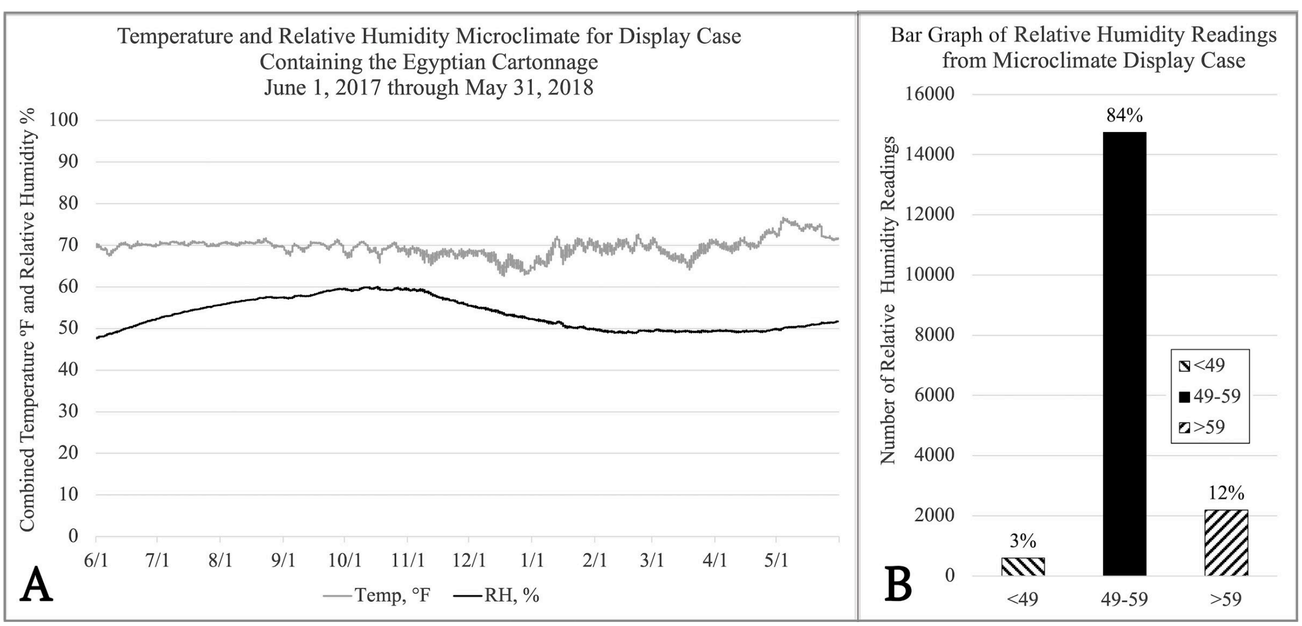


Figure 9. Padimut Microclimate Log and Bar Graph

A- The combined temperature and relative humidity log of 17521 readings taken every 30 minutes from June 2017 through May 2018 for the display case containing the ancient Egyptian cartonnage.

B- A bar graph of the readings showing the successful performance of the micro-climate.

To adjust for this uncertainty we weather-stripped an area of suspected draft and added to each of the six tubs 450 milliliters of saturated magnesium nitrate solution supplying 200 milliliters of water and raising the total available moisture to three liters for the case. As of this writing the micro-climate display case continues functioning well 18 years after installation of the magnesium nitrate hexahydrate tubs in 2005.

Case 2: A Storage Case in a Forced Air Environment

Through its program in historical archaeology the Fiske Center for Archaeological Research in conjunction with the Anthropology Department at the University of Massachusetts at Boston excavates, conserves, and curates archaeological collections composed of a variety of humidity sensitive materials including unstable metals and fragmentary organics composed of wood, ivory, leather, and textiles.

Located in a coastal north temperate climate, the facilities are served by a building-wide HVAC system that is designed to provide comfort cooling only. There is no control of relative humidity. In fact, to maintain a comfortable 72ºF (20ºC) temperature water mists are routinely injected into the ducted air streams to lower the temperature through evaporative cooling. This causes wild year-round instability in the room humidity. The most recent datalog is shown in Figure 10.

Because we wanted to monitor the rapidity with which the room humidity changed we took readings every ten minutes leading to 57228 readings for several years. These showed that it was not uncommon for the relative humidity in the room to change by 10% in one hour and occasionally up to 20% per hour.

While temperature was held near constant, the annual extremes in relative humidity also varied greatly from under 5% to over 80%. A bar graph of those readings shows that only 9% were within the proposed acceptable range of the micro-climate of 54% +/-5%.

In 1998 two micro-climate storage cases were installed to address these humidity fluctuations. One case provides a constant low-humidity environment for the unstable metals using desiccating silica gel and the other, the subject of this case study, provides a constant mid-range relative humidity level for the organics using saturated magnesium nitrate hexahydrate.

Figure 11. Delta Designs Cabinet Closed and Open

A- The closed Delta Designs DDLX-G storage case.
B- The same case opened to show the location of four tubs of saturated magnesium nitrate hexahydrate solution used to maintain the micro-climate range of 49% to 59% RH for over thirty years.

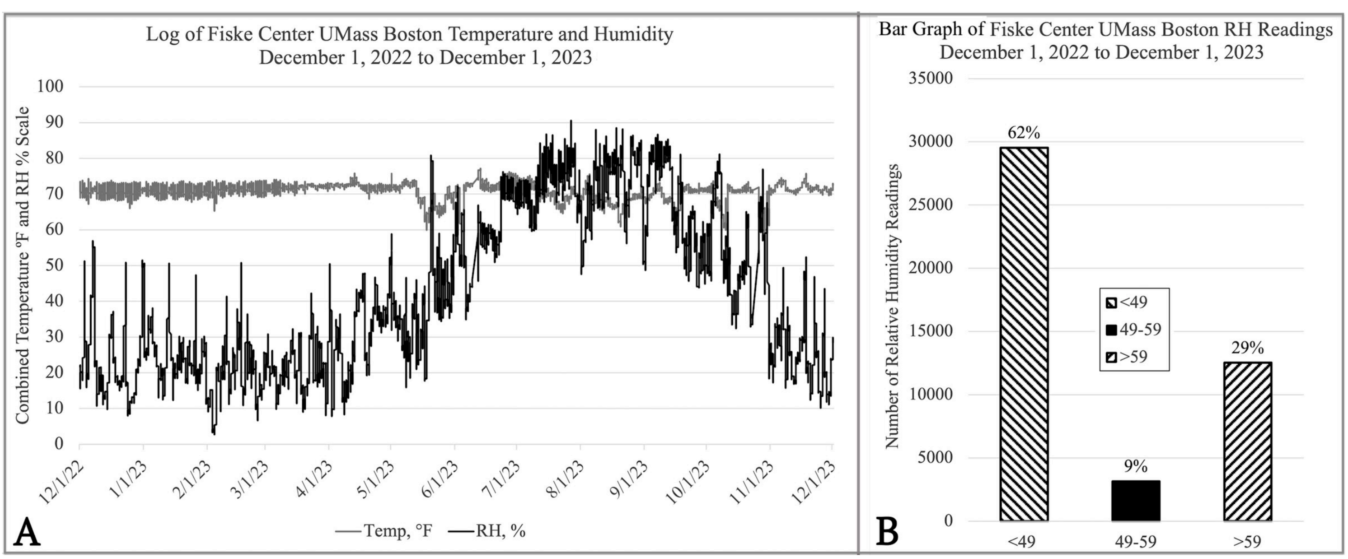


Figure 10. Fiske Center Lab Air and Bar Graph

A- The combined temperature and relative humidity log for 57228 readings taken every 10 minutes from December 1, 2022 to December 1, 2023, for the room containing the storage cabinet filled with sensitive archaeological organics. Typical of ‘comfort cooling’ systems, note the tight control of temperature and extreme daily variability in humidity caused by the use of water mists sprayed into the ductwork of the HVAC system to control temperature through evaporative cooling.
B- A bar graph of the relative humidity readings shown in A. Note that only 9% of the readings fell within the target range of 49-59% RH. (Source: Onset Hobo Model UX100-011A with +/-2.5% RH accuracy.)

A Delta Designs storage cabinet, specifically Model DDLX-G with exterior dimensions of 58” wide by 32” deep by 79” high (147 cm x 81 cm x 200 cm), was chosen for its archival construction and air tightness. The cabinet is fitted with glass doors, four pull-out shelves, and one fixed shelf and has an internal air volume of approximately two cubic meters (Figure 11).

Four Rubbermaid brand tubs, each fitted with Tyvek vapor-permeable membranes as described above, were installed on the bottom shelf of the storage cabinet. Initially the micro-climate performance was monitored only by spot readings of calibrated hygrometers placed in the room and within the case on the upper and lower shelves. Starting in 2005 these were replaced by a single continuously monitoring datalogger (Onset Hobo Model UX100-011A) placed on a middle shelf. While there was an expected and consistent 2% difference between the upper and lower shelves due to still air stratification, it was generally within the error range of the logger and within the allowable range for the micro-climate.

The tubs were partially filled with saturated magnesium nitrate slurry. In 1998 we used a 3:1 ratio of salt to water, specifically, each tub was filled with 1500 grams of magnesium nitrate hexahydrate mixed with 500 milliliters of deionized water to give a slurry weight of 2000 gram occupying 1.5 liters of the tub.

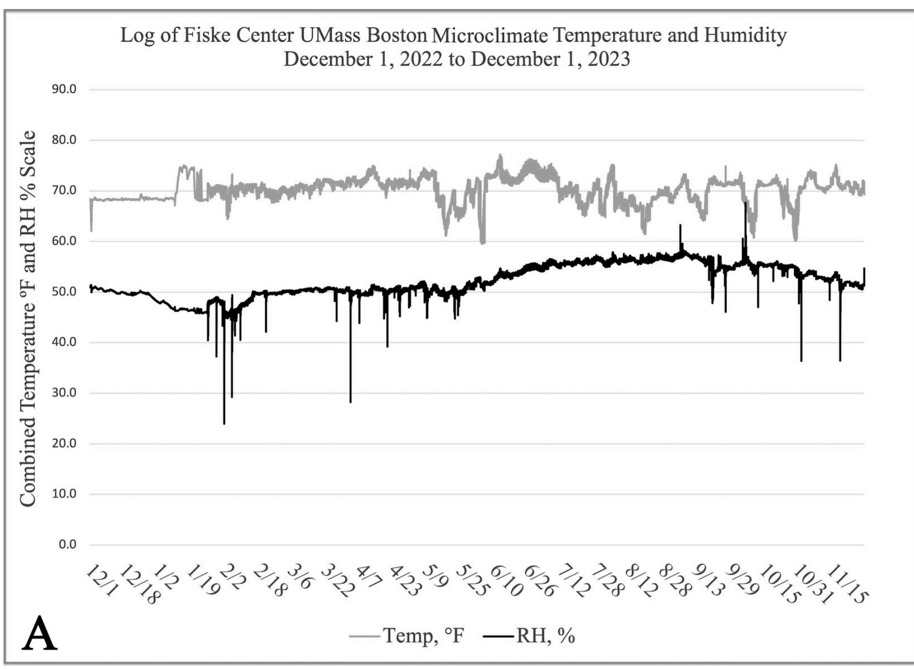
This volume, though less than 20% of the tub’s capacity, was selected to give ample interior wall height to accommodate the inevitable growth of "creeping" salts. While this is often cited as a major issue, our experience, with saturated magnesium nitrate hexahydrate at least, has since shown that with this lidded tub design the salts are contained, and one can safely double the volume of salt solution to just under half of its capacity (Figure 12).

The micro-climate has functioned very well since its installation. The most recent relative humidity datalogs are representative of its performance. While only 9% of the readings of the surrounding room’s relative humidity fell within the target range of 49% to 59%, over 86% of the cabinet readings are within that range. The rate of relative humidity change in the closed cabinet was typically nil to a maximum of 1% per hour. Only when the cabinet is opened does the humidity change abruptly or depart from the target range.

Unlike display cases, artifacts in storage are usually nested, Matrushka-like within multiple archival boxes and packing that themselves have a buffering capability that becomes equilibrated to the target range. To increase that buffering capacity and shorten the re-equilibration time we have added sheets of Artsorb to quickly return the cabinet back to the target range maintained by the salt solution once the doors are reclosed.

Products like Artsorb sheeting are fast-response, low-capacity RH stabilizers. For cabinets that are often opened they work well in conjunction with saturated salt slurries which, in membrane-covered tubs, are high-capacity but slow-response.

While we continue to monitor the tubs annually, we have been surprised that we can go years without needing to refill the lost water. This is in part due to the tightness of the cabinet construction and in part due to the moisture injected into the ductwork of the HVAC system serving the surrounding room for evaporative cooling purposes. That moisture though sudden and erratic has the benefit of slowly replenishing some of the water lost by the micro-climate cabinet during the dry heating season. For this storage cabinet the net moisture loss per year is 500-700 ml and the total capacity of water available from the four tubs is 2000 ml.



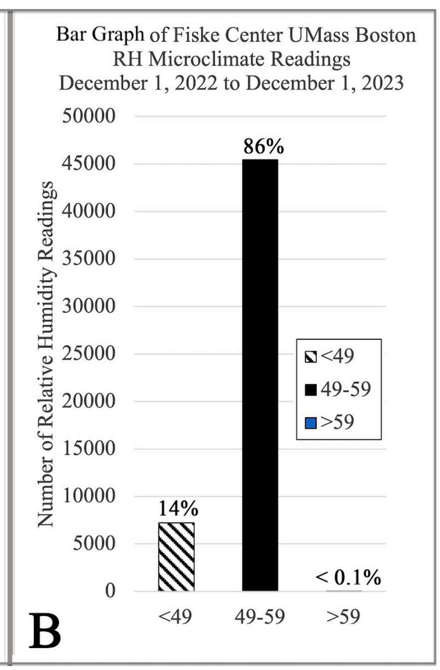


Figure 12. Storage Cabinet Microclimate Log and Bar Graph

A- The combined temperature and relative humidity log for 57228 readings taken every 10 minutes from December 1, 2022 to December 1, 2023 for the storage cabinet filled with sensitive archaeological organics.

B- A bar graph of the readings showing the successful performance of the micro-climate.

Conclusion

During the past three decades we have not seen a rise in the application of saturated salts as a method of microclimate humidity control for collection storage or display. If there were such category in conservation, it might still be classed as a fringe method.

In a sense that is understandable. At first blush the idea of placing wet salts close to collections for their preservation is at least laughably ironic if not simply crazy! And many respected conservation scientists while giving it faint praise have rightly pointed out the risks of certain salts and reiterated the damning notion of uncontrollably creeping salts saying things like, "Eventually the salt gets everywhere" (Padfield, T., ND) or "in spite of the membrane some crystals may find themselves in the case" (Thomson, G., 1991).

Many conservators may simply feel more at home with silica gel and machinery than with the relatively arcane chemistry of saturated salt solutions.

It is our intent to show that, like all conservation methods, the use of magnesium nitrate hexahydrate has measurable risks that can indeed be controlled. We hope that our three decades of safe use with the examples of two case studies has helped to make this point.

Further we hope that our step-by-step procedures would help overcome some of the uncertainty one feels when thinking of installing these solutions. Finally we would like to give a shout out to Gerhard Eggert and his colleagues whose project to develop a global collaboration to address the application of this method deserves all of our support (Eggert, 2023). In a world that demands sustainability its time has come.

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Notes on Magnesium Nitrate Hexahydrate

Standard solubility measurements, the ones one finds online or in chemical handbooks, generally cite the unhydrated mineral weight only, which for magnesium nitrate has a molar mass (weight per mole) of 148.3 grams. The molar mass of the hexahydrate, the form one actually weighs during the preparation of saturated solutions, includes the added weight of 108 grams of hydrated water so its molar mass is 256.4 grams. This equals a maximum solubility of 4.73 moles per liter of water (Saltwiki, 2023). In practical terms at 20º C this means that the weight of magnesium nitrate hexahydrate one measures at saturation must be at least 1213 grams per liter (256.4 grams x 4.73). One then adds to that minimum weight to gain concentrations that insure control during long periods of humid conditions.

Magnesium nitrate hexahydrate is an oxidizing agent. When it is completely desiccated and in contact with an already burning material, it can increase that material's burn rate. For firefighting at industrial and laboratory sites where large amounts of desiccated magnesium nitrate hexahydrate may be stored this is a concern. However under ambient museum conditions with applications to maintain mid-range relative humidity, complete desiccation is rare. In the past three decades of our use this has not occurred. Still you may wish to check with your local fire agency concerning whether and how you may need to alert responding fire fighters of its presence.

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