The benefits and disadvantages of adding silica gel to microclimate packages for panel paintings

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Abstract

Microclimate packages frequently are used for paintings exhibited in less-than-ideal environments. In order to minimize adverse effects caused by leakage, silica gel is added by some conservators to buffer the relative humidity. Concern has arisen that the difference between the adsorption properties of silica gel and the materials in panel paintings might cause damage during temperature changes. To evaluate this question, a research project was undertaken to study the behaviour of panel paintings in microclimate packages with silica gel and panel paintings in microclimate packages without silica gel, observing their dimensional behaviour during fluctuations in temperature. Various silica gels were tested. Additionally, panel paintings within microclimate packages were monitored with dataloggers while in shipment and on loan to other institutions. Results indicate that while silica gel is probably not necessary in well-designed and well-constructed packages, adding a moderate quantity of silica gel to microclimate packages used for panel paintings incurs no increased risks and may prove beneficial when a package has a higher than anticipated air exchange rate.

Introduction

The idea is not a new one—that of encasing paintings in sealed environments. [1] Many terms have been applied—clima-box, microclimate case, microclimate vitrine—but the designation presently used at the National Gallery of Art, Washington, is “microclimate package.” [2] In this paper, the term microclimate package refers to enclosures housing only the painting, containing relatively small quantities of air, and typically fitting within the frame rabbet.

A number of institutions have used microclimate packages routinely for panel paintings loaned to venues with less-than-ideal environments. Their value is so widely accepted that some conservators recommend them solely to minimize environmental fluctuations during transit, when in fact adequate protection can be provided by using well-insulated packing cases and by wrapping paintings in vapor barrier materials, such as polyethylene. [3] But while microclimate packages have been used extensively, the inclusion of silica gel has been a subject of debate. This paper will address the benefits and disadvantages of employing silica gel in microclimate packages.

Thermal response of painting materials

Dimensional responses of painting materials to temperature fluctuations often are ignored because the effects of relative humidity [RH] are greater. But temperature should be considered in transit situations. Most materials expand and contract in response to temperature variations, and linear thermal expansion coefficients have been derived experimentally for many painting materials. A few coefficients are provided in Table 1.

Nathan Stolow studied the physical properties of hygroscopic materials and methods to control environmental conditions inside packing cases containing works of art during transit. He concluded that packing cases should be insulated to minimize temperature changes and large quantities of silica gel should be used to stabilize RH. [8] Stolow determined that temperature changes have a negligible effect on the EMC of silica gel and thus,

Material	Linear Thermal Expansion Coefficient (x 10^{-6} per °C)
White oak, *Quercus alba*, longitudinal	0.3
White oak, *Quercus alba*, radial	32
White oak, *Quercus alba*, tangential	40
Oil paint, white lead	44
Oil paint, yellow ochre	64
Oil paint, Naples yellow	52
Rabbit skin glue	29
Copper	17
Aluminum T-2024	23

Table 1. Linear thermal expansion coefficients for various painting materials. Calculation of the thermal expansion coefficient for white oak, Quercus alba, assumes an average specific gravity of 0.62. (Coefficients for oil paint and rabbit skin glue provided by Marion Mecklenburg, Smithsonian Institution.)

silica gel would stabilize the RH within sealed cases even with temperature fluctuations during transit. [9] It is worth noting that Stolow based this conclusion on the properties of only one type of regular density silica gel. His conclusion that temperature has a negligible effect on the EMC of silica gel is not valid, however, for all types of gel. [10]

Some scientists did not agree with Stolow's recommendation to use silica gel in cases exposed to temperature fluctuations. [11, 12] Silica gel has the capacity to adsorb and desorb large quantities of moisture as compared to most hygroscopic materials found in works of art. Differences in this response to environmental variations could cause materials to gain or lose unacceptable quantities of moisture. If temperature variations produced a significant migration of moisture between silica gel and a panel painting, it could lead to potentially damaging dimensional changes. Results obtained in this research, however, indicate that an adverse effect on panel paintings is highly unlikely with the moderate quantity of silica gel typically included in microclimate packages.

Again, it is useful to consider a hypothetical example. White oak has a linear expansion coefficient of 0.0018 per one percent change in moisture content. If a quarter-sawn one-metre-wide panel is moved from 50% to 40% RH at 20°C, its EMC would drop from 11% to 9.3%, resulting in shrinkage across the grain of approximately 3.1 mm.

Foil strain gauges of 1.25 cm length were adhered with cellulose nitrate cement on the reverse of each panel, perpendicular to the grain. Strain gauges were also adhered to aluminum alloy T-2024 and titanium silicate samples that were used as controls to ensure accurate data handling. In order to understand the environmental conditions within the packages and the consequent responses of the wood panels, over thirty experiments were conducted to evaluate the effects of several types of silica gel, various package volumes, different temperature fluctuations, and assorted exposure periods. In addition, many panel paintings inside microclimate packages were monitored with dataloggers while in transit and on loan to other institutions.

While dimensional changes that accompany temperature variations in the longitudinal direction of the wood are extremely small, the expansion coefficients of oak in the radial and tangential directions are greater. Note that the coefficients for radially and tangentially cut wood are close to the coefficients of oil paint and rabbit skin glue and greater than copper and aluminum. In the longitudinal direction, wood restrains the thermal response of the glue and paint layers, increasing stress between the layers.

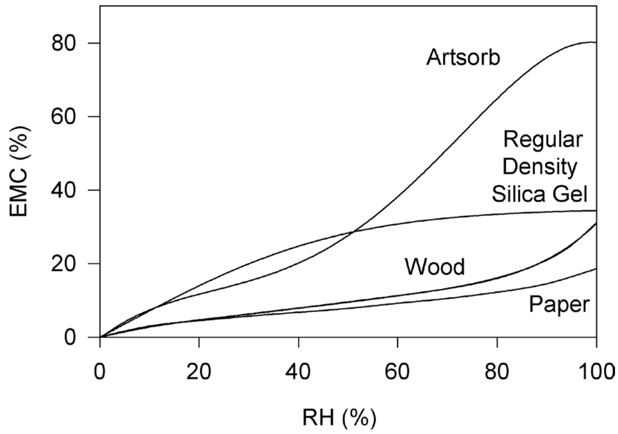

Figure 1. Moisture sorption isotherms of a few hygroscopic materials at 20°C.

A good way to grasp the significance of these numbers is to consider the dimensional changes of a hypothetical painting on white oak panel during transit. A quarter-sawn one-meter-wide white oak panel in a well-sealed microclimate package will theoretically contract by 0.64 mm across the grain when the temperature drops from 20°C to 0°C. For comparison, the same shrinkage would occur with a drop in RH from 50% to 47.7%. This is a relatively small dimensional change, but one which happens very rapidly when induced by varying temperature.

Equilibrium moisture content

Hygroscopic materials—wood, paper and silica gel—adsorb or desorb moisture until they attain equilibrium with the surrounding RH. At a fixed temperature, the equilibrium moisture contents (EMC) of materials as a function of RH are called isotherms (see Figure 1).

The EMC of hygroscopic materials is affected not only by RH but also by temperature and pressure. It is generally accepted that the pressure effects on the moisture content of materials sealed within microclimate packages are so negligible as to be ignored, even in the case of air shipments. Temperature effects, however, can be significant and should not be overlooked. At a constant ambient RH, increasing the temperature drives off moisture but water vapour is adsorbed when the temperature decreases. In a stable RH environment, wood will have a higher EMC at 15°C than at 25°C. A panel painting displayed in a gallery maintained at 25°C and 50% RH will have

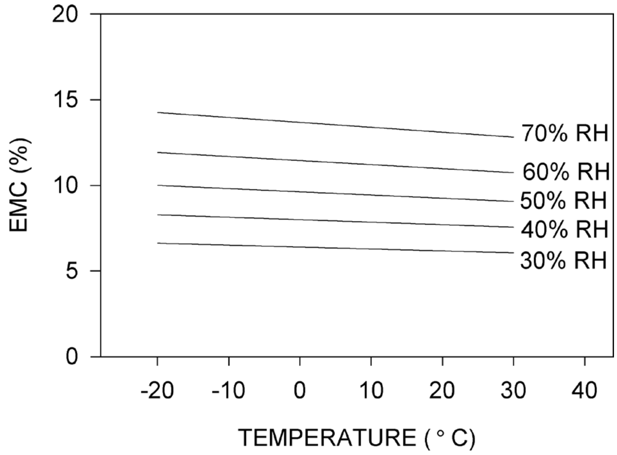

Figure 2. Relationship between temperature and the equilibrium moisture content of wood at several relative humidities.

an EMC of approximately 9.14%. If the temperature were to drop to 15°C while the humidity remained at 50% RH, the moisture content of the wood would gradually increase to 9.34%. The relationship between temperature and the EMC of wood at fixed RH levels is illustrated in Figure 2. [4]

The circumstances in a microclimate package are quite different, because the package's small air volume offers little moisture for adsorption. [5,6,7] In moving from 25°C to 15°C, equilibrium is re-established at approximately 48.5% RH, assuming a high ratio of wood volume to air space. A tiny quantity of moisture is actually adsorbed by the cooling wood in reaching equilibrium at the lower RH level, having virtually no effect on the EMC of the wood unless another source of moisture is available. To state this another way, a tightly wrapped piece of wood exchanges moisture with the surrounding air until an equilibrium RH is attained that is appropriate for the moisture content of the wood and the temperature. When the temperature changes, the process is repeated and a new equilibrium RH will be established within the wrapped air space.

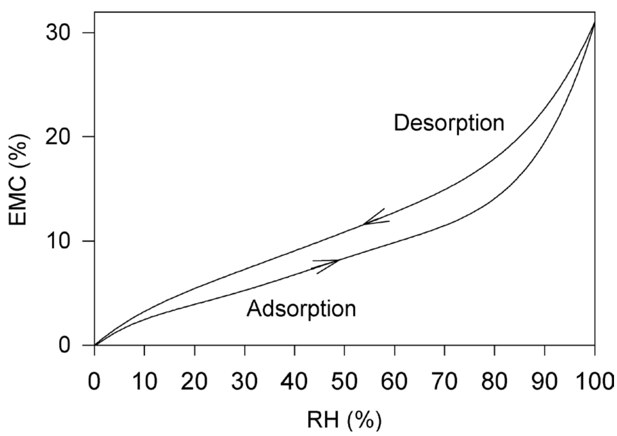

Figure 3. Moisture adsorption and desorption isotherms of wood at 20°C.

Hysteresis

The EMC of hygroscopic materials is not only dependent on temperature and RH but on whether equilibrium is approached from a drier or a damper environment, a phenomenon called hysteresis. A hygroscopic material moved from a dry to a damp environment will arrive at a lower EMC than one moved from a damp environment to a dry one. Similarly, materials adsorbing moisture as the temperature declines will not return to precisely the same EMC when the temperature rises. The typical hysteresis behaviour of wood is shown in Figure 3. The lower adsorption line represents the results of placing a dry piece of wood in a progressively damper environment while the upper desorption curve corresponds to the opposite situation, placing a saturated piece of wood in a progressively drier environment.

The two curves in Figure 3 define a region of the graph known as the hysteresis loop. The curves serve as the boundary lines for an infinite number of EMC points that can result from moving wood between different RH environments at constant temperature. The hysteresis loop is much smaller when wood is moved within lesser RH ranges, as seen in Figure 4 when wood oscillates between 30% and 70% RH environments. Silica gels exhibit pronounced hysteresis between 30% and 70% RH. Given that temperature changes will have an effect on the sorption properties of these materials as well, the exact point at which the moisture content of a wooden panel in a microclimate package comes to rest during transit is scarcely predictable. While it is important to recognize that hysteresis affects the EMC of wood exposed to changing environments, it seems unlikely that it plays a significant role in the behaviour of panel paintings enclosed in microclimate packages.

Dimensional changes due to moisture

Dimensional changes in wood caused by variations in moisture content are anisotropic, that is, of different magnitude in the longitudinal, radial, and tangential directions. As with temperature variations, dimensional responses to moisture variations in the longitudinal direction are very small. Within moisture content limits of 6% to 14%, wood's linear expansion coefficient per one percent change in moisture content varies from 0.002 to 0.0045 (Δ length/length) in the tangential direction and from 0.001 to 0.003 in the radial direction.

All materials in traditional panel paintings are affected by fluctuations in temperature and relative

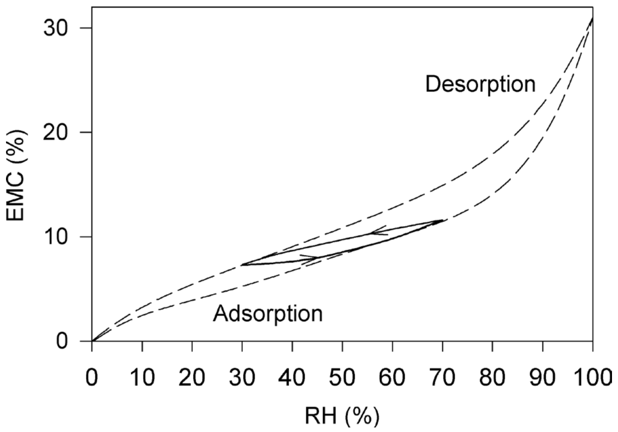

Figure 4. Moisture sorption hysteresis loop for wood between 30% and 70% RH at 20°C.

humidity. Wood's response, as already noted, is anisotropic while paint, ground, and glue size behave isotropically; they swell and shrink equally in all directions. Wood's swelling in the radial and tangential directions, as a result of relative humidity changes, is greater than that of glue size, gesso, or paint. It is significant enough that cracks in the various painting layers can develop parallel to the grain because of stress imposed on them by excessive movement of the wood. In the longitudinal direction, there is very little expansion or contraction of wood due to relative humidity changes. Since the glue size, gesso, and paint respond in all directions, the dimensional movement of these materials is restrained by the longitudinal wood when the relative humidity changes. The stress resulting from this restraint can cause formation of cracks perpendicular to the wood grain during desiccation. [13]

EXPERIMENTAL RESULTS AND DISCUSSION

One means to a better understanding of the behaviour of panel paintings within microclimate packages is to measure dimensional changes in wood panels using foil strain gauges. These small devices exhibit predictable changes in electrical resistance when stretched or compressed. Experience has shown that strain gauges work well for measuring the overall dimensional activity of quarter-sawn wood, provided the grain is reasonably uniform. They work less well with samples cut from wood sawn in other planes, and on wood with knots, cracks, or irregularities in the grain.

Experiments were performed on three quarter-sawn oak panels. The reverse of the panels had no coatings, battens, or cradles, which would alter the panel's behaviour. The first was a North American oil painting on white oak panel (c. 1900) measuring 0.25 x 0.20 x 0.014 m thick. The second was a watercolour on paper adhered to an oak panel (unknown species) estimated to be at least two hundred years old and measuring 0.48 x 0.27 m x 0.01 m thick. The third was a panel—its obverse coated with a traditional calcium carbonate gesso plus two layers of Acryloid B-72—made ten years ago from white oak flooring removed during renovation at the National Gallery of Art. It measures 0.61 x 0.40 x 0.006 m thick. In all instances, the panels were mounted inside the microclimate packages with two small polyethylene foam pads. This is significantly less support than normally used in microclimate packages, but the intention was to ensure that the mounts did not restrict the movement of the wood. Generally, the experiments were conducted with the panels positioned with the grain direction vertical, although tests showed that orientation had no effect on the results.

MICROCLIMATE PACKAGES WITHOUT SILICA GEL

Several experiments were conducted to evaluate the effects of environmental fluctuations on the dimensional responses of oak panels in microclimate packages without added buffering materials. Three packages with interior dimensions of 0.262 x 0.207 x 0.016 m; 0.417 x 0.281 x 0.032 m; and 0.619 x 0.41 x 0.036 m were acclimatised to 20°C and 50% RH for several days before dropping the temperature to 0°C.

The temperature and RH responses within the three packages were very similar, and are thus represented by single curves in Figure 5. The interior temperature dropped at virtually the same rate as the environmental chamber. The relative humidity initially increased slightly and then dropped until equilibrium was established at a lower RH. With rapid temperature changes, several factors might contribute to the observed initial rise in RH: transient temperature and RH gradients that would develop within the packages; the air would cool more quickly than the panel, possibly allowing the RH to increase before the wood began to adsorb moisture; and/or the rapidly-cooling metal housing of the RH sensor might have caused an anomalous response in the early stages of the experiments.

Figure 6 is a graph of the percent length change of the three oak panels inside their microclimate packages. For comparison, curves for the temperature-induced dimensional changes of the aluminum alloy T-2024 and the theoretical response of radially-cut white oak are provided. Moisture adsorption is not a determining factor because the only source of water is in the surrounding air. After a tiny quantity of

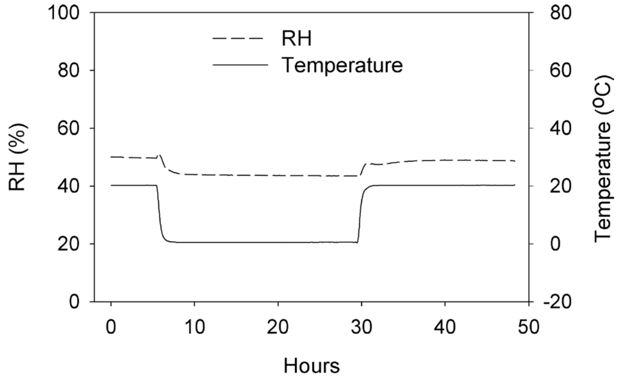

Figure 5. Temperature and RH inside a microclimate package containing an oak panel but without silica gel.

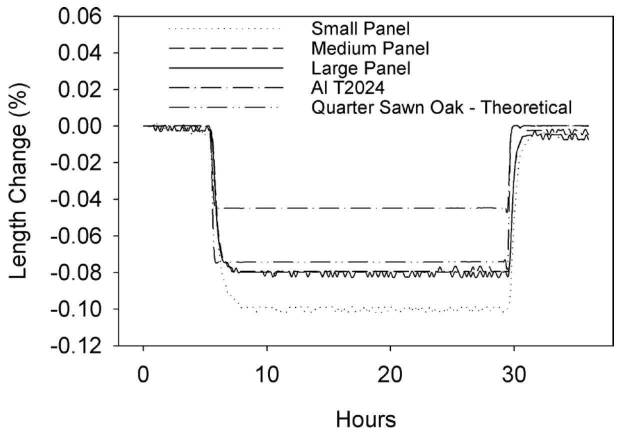

Figure 6. Percent length change (ΔL/L) of oak panels inside microclimate packages (without silica gel) during temperature fluctuations. For comparison, curves are provided for aluminum alloy, T-2024 and for the theoretical dimensional change of quarter-sawn oak.

water from the air is absorbed, equilibrium is re-established at a slightly lower RH. As evident in the curves, shrinkage of the wood occurred quickly and remained constant until the temperature was raised. Similar experiments were conducted to evaluate the impact of a 20°C temperature rise and a 40°C temperature drop, yielding proportional results.

Microclimate packages with silica gel

Multiple experiments were designed to evaluate the impact of adding silica gel to the packages. Different types and diverse quantities of gel were placed inside microclimate packages and exposed to a variety of test parameters. To illustrate, two experimental runs that included Artsorb beads have been selected. Artsorb beads were enclosed in a panel made of a polystyrene lighting diffuser covered with polyester screening. The silica gel used in the three panels weighed 187 g, 504 g, and 980 g when conditioned to 50% RH.

The experimental procedure was identical to the one described earlier, except the depth of the microclimate packages was increased to accommodate the silica gel panels. Interior dimensions of the packages were 0.262 x 0.207 x 0.022 m, 0.417 x 0.281 x 0.038 m, and 0.619 x 0.41 x 0.042 m. Results for a drop from 20°C to 0°C can be seen in Figures 7 and 8. The temperature change inside the packages was identical to the previous example, but the spike in relative humidity was slightly greater.

Various silica gels were evaluated, yielding similar results. Anomalies did appear, not in the pattern of behaviour, but in the degree of the temporary humidity change accompanying a rapid rise or fall in temperature.

Once again, the wood panels shrank in response to the dropping temperature. The degree of initial shrinkage was slightly less than observed in the packages without silica gel but it did not remain constant. The wood gradually expanded during the 24 hour exposure to 0°C, recovering 10% of the initial shrinkage caused by temperature. That is comparable to a 0.25% change in RH. Other experiments demonstrated that the results varied with package volume, type of silica gel, quantity of gel, degree of temperature change,

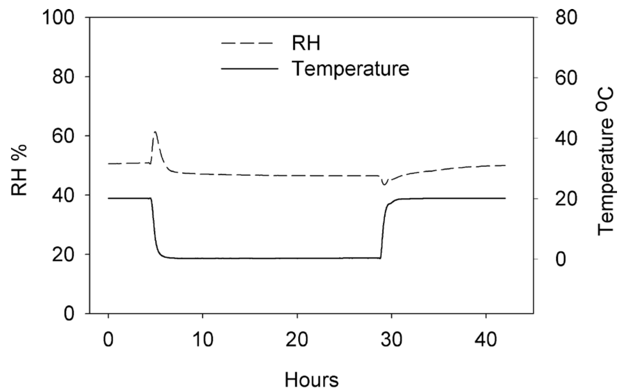

Figure 7. Temperature and relative humidity conditions within a microclimate package containing an oak panel and Artsorb.

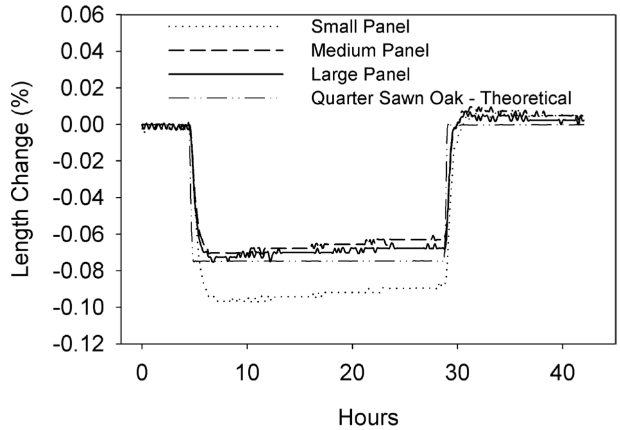

Figure 8. Percent length change (ΔL/L) of oak panels inside microclimate packages (with Artsorb) during temperature fluctuations. For comparison, curves are provided for the theoretical dimensional change of quarter-sawn oak.

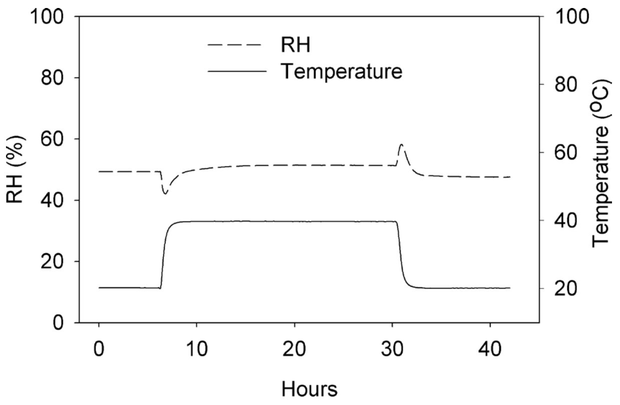

Figure 9. Temperature and relative humidity conditions within a microclimate package containing an oak panel and Artsorb.

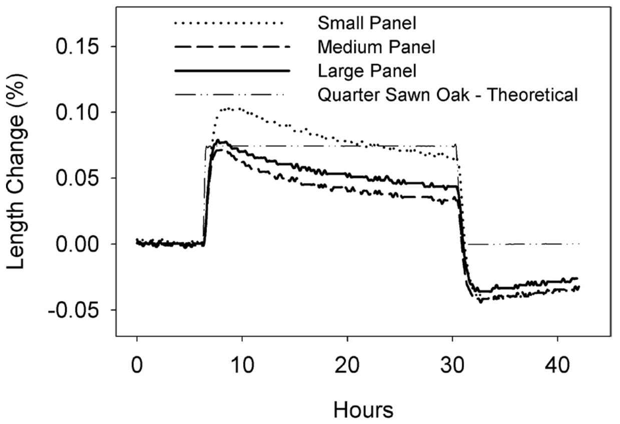

Figure 10. Percent length change (ΔL/L) of oak panels inside microclimate packages (with Artsorb) during temperature fluctuations. For comparison, curves are provided for the theoretical dimensional change of quarter-sawn oak.

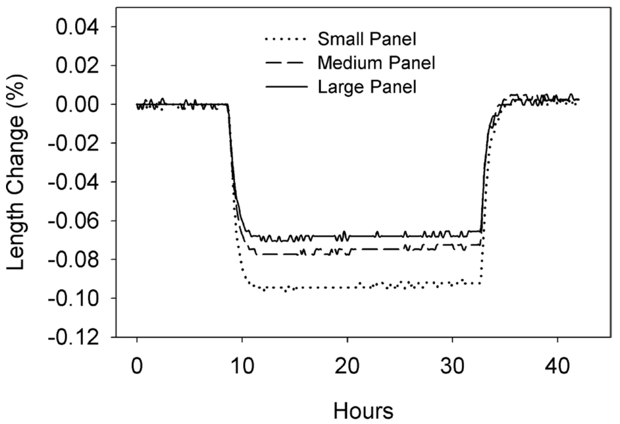

Figure 11. Percent change in length (ΔL/L x 100) of oak panels inside microclimate packages (with Rhapid Gel) during 20°C variations.

and exposure period. However, the expansion due to moisture adsorption was always considerably smaller than shrinkage caused by the drop in temperature.

Response rates tend to be faster at higher temperatures, clearly visible in Figures 9 and 10. The pattern is a simple reverse of the cooling cycle with changes occurring more quickly.

Various sheet materials consisting of silica gel embedded in paper or synthetic fibres were tested

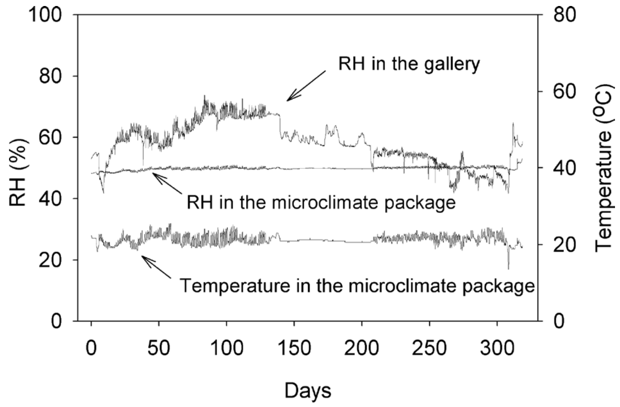

Figure 12. Environmental conditions inside and outside a microclimate package for an Italian renaissance panel painting (with Artsorb) while on loan to two museums.

with similar results. Figure 11 provides curves for the dimensional response of three microclimate packages containing a sheet of Rhapid Gel. Per unit weight, Rhapid Gel has buffering properties similar to Artsorb, but a single sheet contains a much smaller quantity of gel. The pattern of shrinkage was similar. However, less dimensional recovery was observed.

Environmental conditions in microclimate packages for paintings on loan

Many paintings loaned by the National Gallery of Art during the last twenty years have travelled in microclimate packages. In some instances, environmental conditions – both inside and outside these packages – were monitored with dataloggers. Figure 12 provides data pertaining to the loan of an Italian renaissance painting on wood exhibited at two venues. Conditions in the galleries were less than ideal, but the painting's environment within the microclimate package remained nearly stable. Small daily fluctuations, reflected in Figure 12, are almost certainly due to temperature changes caused by gallery lighting.

Conclusions

Temperature variations cause rapid dimensional changes in painting materials, including wood panels. The expansion and contraction of wood resulting from temperature variations is small, as compared to the effects of RH change within normal everyday extremes. Indeed, a 20°C temperature variation is equivalent to only an approximate 2.3% RH change. Panel paintings displayed on museum walls are regularly exposed to larger fluctuations in relative humidity without damage.

This research confirms that microclimate packages are beneficial for panel paintings being loaned to institutions with less-than-ideal environments. Similarly, we can presume that microclimate packages work equally well for paintings on fabric supports. Well-constructed microclimate packages containing minimal air will maintain a stable relative humidity without adding silica gel, provided there is little leakage. The addition of a moderate quantity of conditioned silica gel will improve the performance of microclimate packages having a significant leakage rate. While there may be situations where temperature-induced differences in adsorption could adversely affect some materials, it is unlikely that this phenomenon poses a serious risk to the stability of panel paintings.

Suppliers

Artsorb:

Fuji Silysia Chemical, S. A.,
2-1846 Kozoji-cho, Kasugai-shi, Aichi-ken,
JAPAN 487-0013.

Rhapid Gel:

Art Preservation Services, 315 East 89th Street,
New York, NY 10128, USA.

SR-4® Strain Gages:

Vishay BLH, Vishay Micro-Measurements,
PO Box 27777, Raleigh, NC 27611, USA.

Metrosonics Model 721 Datalogger:

Metrosonics, Inc., 1060 Corporate Center Drive,
Oconomowoc, WI 53066, USA
(no longer available).

Temperature/Relative Humidity Transmitters (model 850):

General Eastern Inc., GE Sensing, 1100
Technology Park Dr., Billerica, MA 01821, USA.

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Endnotes

1 Wadum, J., 'Microclimate Boxes for Panel Paintings', in *The Structural Conservation of Panel Paintings, Proceedings of a Symposium at the J. Paul Getty Museum, April 1995*, ed. K. Dardes and A. Rothe, The Getty Conservation Institute: Los Angeles (1995) 497-524.

2 The National Gallery of Art has used flexible laminated moisture barrier films, such as Marvel-seal, for microclimate packages since 1992.

3 Richard, M., 'Control of Temperature and Relative Humidity in Packing Cases', in *Art in Transit: Studies in the Transport of Paintings*, ed. M. F. Mecklenburg, National Gallery of Art: Washington (1991) 279-297.

4 *Handbook of Wood and Wood-based Materials for Engineers, Architects, and Builders*, Published for the Forest Products Laboratory, U.S. Department of Agriculture, by Hemisphere Publishing, New York (1987) 3-11.

5 Thomson, G., 'Relative Humidity: Variation with Temperature in a Case Containing Wood', *Studies in Conservation*, 9 (1964) 153-169.

6 Thomson, G., 'Stabilization of RH in Exhibition Cases: Hygrometric Half-Time', *Studies in Conservation*, 22 (1977) 85-102.

7 Stolow, N., *Conservation and Exhibitions*, Butterworths, London (1987) 126-130.

8 Stolow, N., *Controlled Environment for Works of Art in Transit*, published for the International Institute for Conservation of Historic and Artistic Works and the International Centre for the Study of the Conservation of Cultural Property by Butterworths, London (1966) 42-44.

9 Stolow (1966) 11.

10 The author currently is investigating the adsorption properties of various desiccants.

11 Hackney, S., 'The Dimensional Stability of Paintings in Transit', in *ICOM Committee for Conservation, 8th Triennial Meeting, Sydney, Australia, 6-11 September 1987*: Preprints, ed. K Grimstad, The Getty Conservation Institute, Los Angeles (1987) 597-600.

12 Toishi, K.J. and T. Gotoh, 'A Note on the Movement of Moisture Between Components in a Sealed Package', *Studies in Conservation*, 39 (1994) 265–271.

13 Mecklenburg, M. F. and C. S. Tumosa, 'Mechanical Behavior of Paintings Subjected to Changes in Temperature and Relative Humidity', in *Art in Transit: Studies in the Transport of Paintings*, ed. M. F. Mecklenburg, National Gallery of Art: Washington (1991) 279-297.