HOW TO PROTECT GLAZED PICTURES FROM CLIMATIC INSULT

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Abstract. Pictures on paper framed behind glass are at risk from moisture movement caused by temperature gradients, both transient and seasonal. The temperature gradient can be reduced by mounting pictures about 2 cm from the wall and by preventing direct sunlight illuminating the picture. Insulation behind the picture provides no benefit. Sealing the back of the frame greatly improves the moisture stability of the enclosure. An absorbent back board within the sealed space stabilises the picture against changes of ambient RH but destabilises the RH at the picture when transient temperature gradients arise.

1. Introduction

Pictures framed behind glass are at risk from extreme temperature and relative humidity (RH) developing within the shallow enclosure. Even in a modern air conditioned museum, a shaft of sunlight playing briefly on the picture will heat it to over fifty degrees, depending on its colour. A picture hanging against an outside wall may cool so much that condensation accumulates within the frame, as well as on the wall behind.

First we describe the physical principles governing water and vapour distribution in small spaces subjected to a temperature gradient and then we show measured microclimates within picture frames exposed in stressful environments.

There are four physical principles which define the movement and the equilibrium concentrations of water and water vapour within a small, fairly well sealed enclosure containing abundant absorbent material.

1.1. **The RH in a small space is controlled by the absorbent materials within it.** The ratio of the weight of absorbent material to the weight of air within the enclosure is generally so high that it is the water content of the materials that control the water vapour concentration of the air, in contrast to the world outside the enclosure, where the moisture content of the air controls the water content of absorbent materials.

1.2. **The RH depends mainly on the water content of the material.** The RH close to absorbent materials depends on the water content of the material, with little dependence on temperature. There is only a slight decrease in RH at a given water content in cellulose when the temperature drops (Urquhart and Williams 1924).

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1.3. **Water vapour concentration tends to uniformity.** Water vapour tends to diffuse throughout the spaces within an enclosure to give a uniform concentration, rather than a uniform RH. A temperature gradient will therefore automatically generate a RH gradient, because the RH is the ratio of the water vapour concentration at that point to the maximum possible concentration at the temperature of that point. This maximum concentration diminishes steeply with temperature; so if the actual concentration is uniform the RH must be higher in the cooler parts.

1.4. **Water moves in materials to equalise the water content.** When a temperature gradient builds up, the water vapour concentration in the air spaces around absorbent materials will change, even though it will tend towards uniformity throughout the enclosure. This is because absorbent materials do not absorb water in proportion to the increasing RH around them. If the temperature gradient is so large that the RH becomes very high at the cold side, the material will absorb so strongly that the water vapour concentration will be reduced everywhere within the enclosure. If the RH reaches 100% at the cold side, water will be removed by condensation and the water vapour concentration in the air space will be controlled by the temperature of this cold surface. An extreme temperature gradient will therefore cause dehydration of the picture, while dew appears on the glass, or on the back plate.

An important consequence of the operation of these rules is that there is, in a temperature gradient, a cyclic flow of water and vapour in an enclosure containing absorbent material. Water will tend to move within the absorbent material towards the drier warmer parts, where the RH is lower. This movement is slow except close to saturation, when there is accumulation of water in fine capillaries, where it is quite mobile. The water will re-evaporate at some point and diffuse back to re-establish the uniform vapour concentration. It is therefore surprisingly difficult to provoke visible condensation in a container with absorbent material hard up against the cold side.

2. Experiments on the microclimate within glazed prints

Figure 1 shows the structure of the framed prints that we have used for the experiments, and the placing of the sensors. The temperature gradient was measured with thermocouples, 0.2 mm thick at the tip. The RH sensor was about 1.5 mm thick. Its sensitive area, which is only about one square millimetre, is attached to a circuit board 3 x 5 mm, which obstructs the free diffusion and flow of air and vapour. The RH values shown in the graphs should therefore be read as evidence of the process that is occuring rather than as accurate records of the RH that would prevail at that point, without the sensor present.

2.1. **Pictures in an unheated house.** Figure 2 shows the inferior moisture stability of an unsealed picture in an unheated house, compared with two pictures with impermeable backs. The exact trend of the RH traces on the diagram is not significant, because no attempt was made to seal the pictures perfectly. The rapidity with which the unsealed picture came to

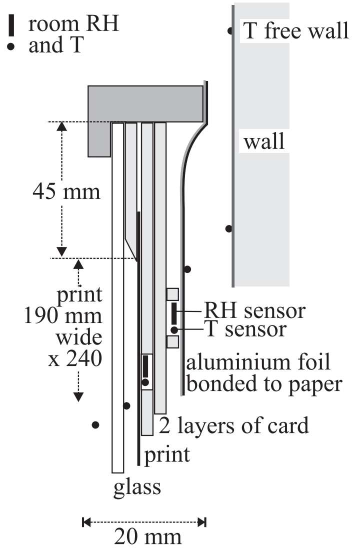

Figure 1. Cross section through the glazed frame of a print which has been fitted with moisture and temperature sensors. All the absorbent materials are cellulose, the frame is of wood. Temperature sensors are black points, RH sensors are short black bars.

equilibrium with the room RH is disturbing, given the uncontrolled climate in this house in the Copenhagen Open Air Museum.

A detail from this diagram is included in figure 3, which reveals a particular danger for unsealed paintings in a high ambient RH. A sudden drop in outside temperature briefly brought the inside wall surface below the dew point of the room air, whose temperature and RH were buffered by the walls and furnishings. The wall just behind the painting was relatively cool, because it was slightly insulated against the inside temperature by the picture itself. This was therefore the place where condensation occurred. This condensation was absorbed into the back board, so that the RH at the picture suddenly rose above ambient. Three such episodes are visible in the graph. The temperature was low, so the picture was also at risk from growth of ice crystals in the very humid paper.

2.2. **Pictures against a cold wall in a heated room.** Our second example is a set of pictures set at varying distances from a cold, poorly insulated outside wall (actually a double glazed window facing north) in a heated room. All the pictures were sealed at the back. The temperature gradients were much greater than in the previous experiment and the cooling effect of the picture on the wall immediately behind it is shown quite clearly in figure 4. The dew point of the room air was 8°C, so a picture hard up against the wall would be vulnerable to condensation within its frame, even if it had long been in equilibrium with the room air. The picture at 6 mm from the wall was entirely above the dew point but the wall behind had condensation. The picture at 20 mm distance from the wall was close to a uniform

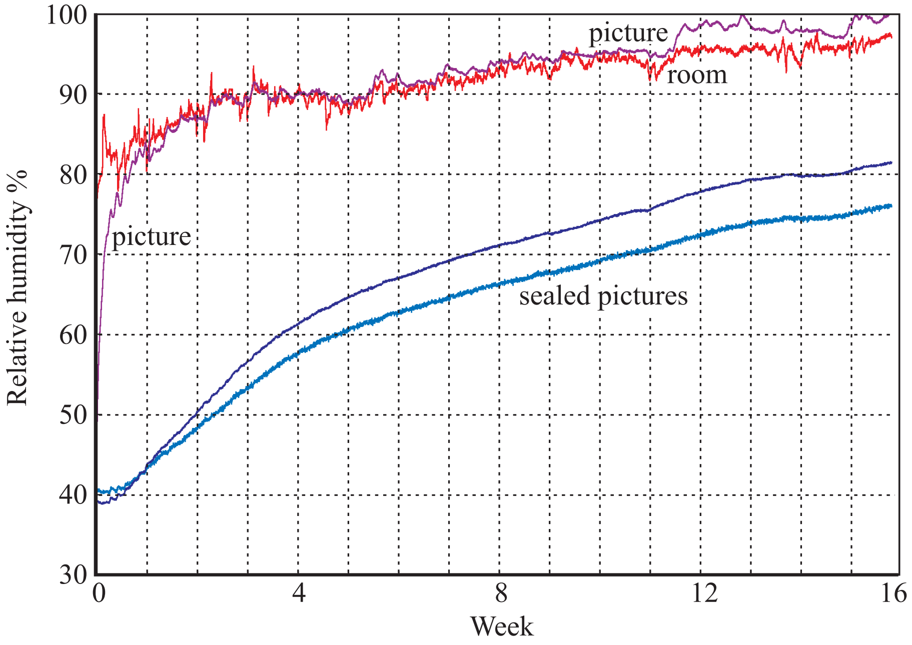

Figure 2. The course of the relative humidity immediately behind the prints in three glazed frames exposed in an unheated house. The indoor RH averaged about 90% during this winter period. One picture had no impermeable backing. It rapidly came to equilibrium with the room air from its starting point at 40% RH. The other two pictures were covered on the back with aluminium coated paper, but were not otherwise sealed with particular care. At the end of the exposure period they were still far from equilibrium with the room air and enjoyed a more stable climate than the unsealed picture.

temperature but the wall behind was still markedly cooler than the general wall temperature.

The climate around the picture mounted against the wall is shown in more detail in figure 5. The RH within the frame was about 80% before the temperature gradient was imposed. When it was put against the cold wall the RH measured just behind the print dropped immediately by 2%. This was a consequence of the slight temperature dependence of water sorption by cellulose. The subsequent downward drift in RH at the print was due to the backboard absorbing water vapour at the high RH towards the cool back of the assembly. This strong absorption by the back board kept the print safely dry, even though the RH within the frame was initially dangerously high.

2.3. **A picture against a thin wall that gets both hot and cold.** In the next experiment, one picture was set against a wall that was alternately cold and warm, typical of the thin, uninsulated wall of a simple hut. The

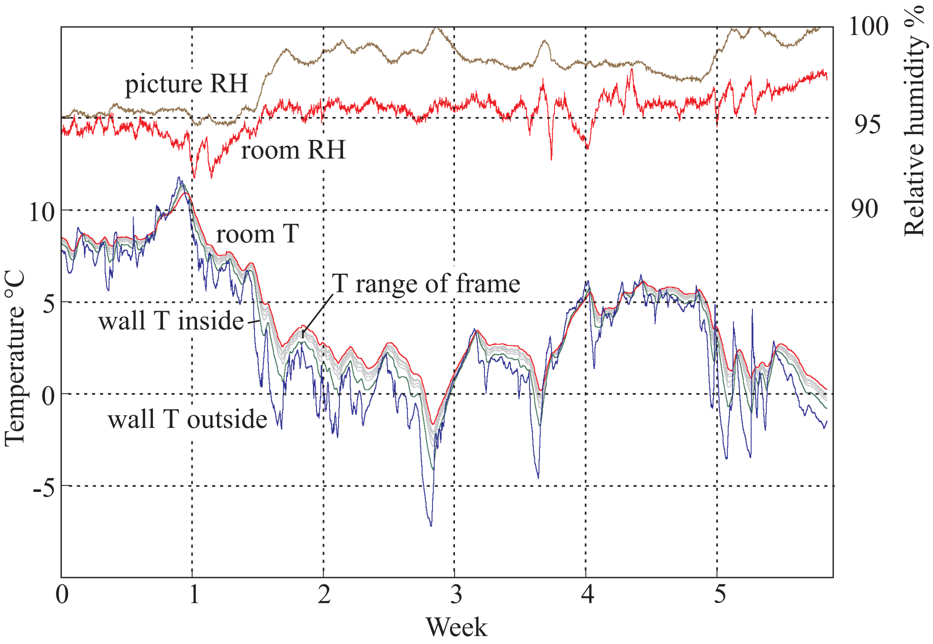

Figure 3. Condensation into the back of an unprotected picture. This is a detailed record from the last 6 weeks shown in figure 2. A sudden drop in outside temperature in the middle of the second week has caused the inside surface of the wall, where it was partly screened by the picture, to fall below the dew point of the room air, which was buffered in temperature and in RH by the building and its furnishings. The condensed moisture has been absorbed into the porous back board of the picture and has caused a sudden but long lasting increase in the RH measured just behind the print.

course of the climate is shown in figure 6. The first night repeated the pattern of figure 5, with the picture drying slightly. Then a period of weak sunlight warmed the wall only slightly above ambient. The relative humidity at the picture rose as water evaporated from the warm mount. The next day brought strong sunlight. The complex pattern of events is spread out in time on the right side of the diagram. There was condensation on the glass, dehydrating the rest of the enclosure, so that both picture and backboard became drier as the heating continued.

2.4. **A picture exposed to sunlight indoors.** Figure 7 shows what happens when sunlight, through a window, plays directly on the picture. At first water moved from the heated print to the backboard but then the backboard also dried out, losing water, probably to the paler, cooler parts near the edges of the frame. During the night the enclosure moved back towards a uniform moisture distribution. The water was not lost, but it took a long time to migrate back parallel to the materials in the frame.

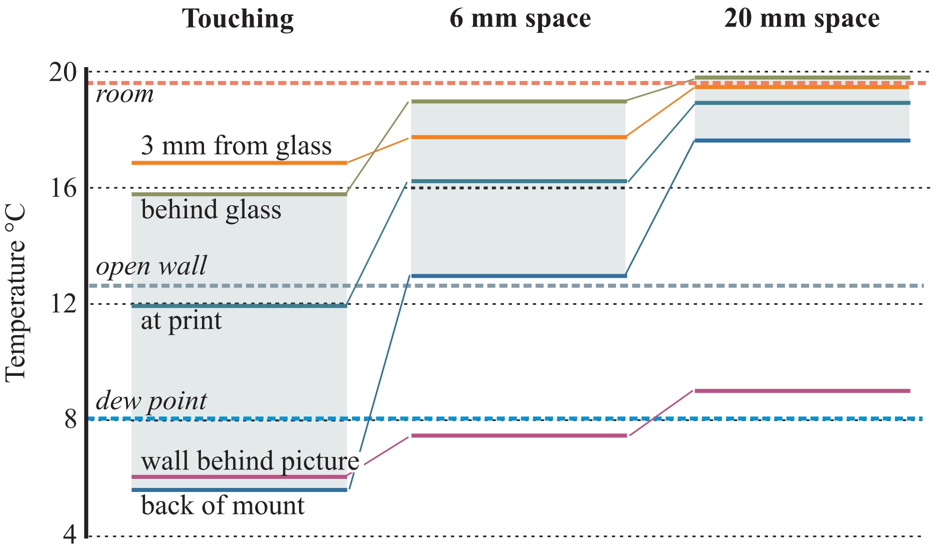

Figure 4. The temperature gradient through three pictures set against a cold outer wall. The shaded areas represent the enclosed air spaces within the frames. Notice that the internal temperature gradient was very small when a 20 mm air gap was established between the back board and the wall. The room dew point was 8°C, so there was condensation on the wall behind the two closest pictures.

3. Discussion

These semi-quantitative demonstrations of the effect of unsteady environments on pictures give an indication of the magnitudes and the rates of the movement of water, both as vapour and as liquid, within and near the shallow enclosure of the picture frame.

3.1. **Direct sunlight causes an extreme microclimate.**

The instability of the microclimate in pictures that are briefly exposed to shafts of sunlight through windows is particularly striking, and leads us to emphasise that ambient climate control in a gallery gives no protection against direct sunlight, particularly on objects enclosed behind glass. Pictures that will unavoidably suffer short periods of direct sunlight, in historic houses for example, should be mounted so that heat can readily be lost from the back, ensuring that the glass is never the coldest part of the assembly.

3.2. **The back of the frame should be sealed.**

There are very few environments where a sealed backboard is more risky than a porous back. An important detail, however, is that the sealing material should be in intimate contact with a porous mat behind the picture. This will prevent accumulation of condensate at the bottom of the frame. Damage by pollutants released within the frame can be avoided by choice of pure cellulosic mounting materials and by sealing a wooden frame with aluminium foil.

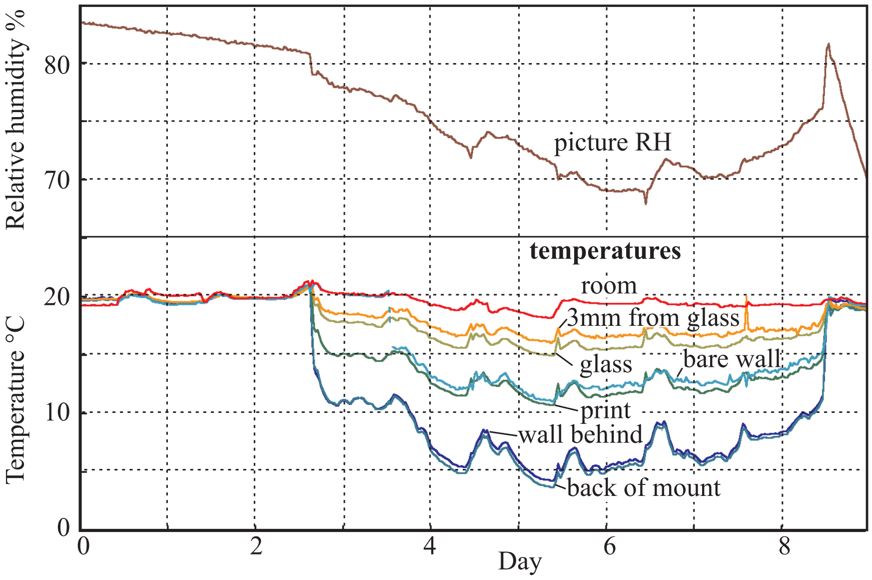

Figure 5. The microclimate in the frame touching the wall. Before the picture was placed against the wall the RH at the print was 80%, drifting slowly towards equilibrium with the 45% RH in the room. As soon as the back of the picture was set against the cold wall the RH dropped. The first very rapid drop, at about day 2.6, is caused by the temperature change at the print. For a given water content, paper is in equilibrium with a lower RH at a lower temperature. The subsequent further fall in RH is caused by moisture transfer to the cooler back board. At the end of the period, day 8.5, the picture was removed from the wall, causing an instant increase in RH, due to the temperature rise at the back and transient absorption into the still cool print. The sealed back plate was immediately opened, revealing abundant condensation on its inner surface.

3.3. **Pictures should be held away from walls.** The microclimate within a picture mounted on an uninsulated outer wall can be vastly improved by establishing a gap large enough to allow indoor air to stream between the back of the picture and the wall. The width of the gap should increase with the size of the picture, but 20 mm seems to be the minimum gap. A smaller gap slows the air stream enough to reduce the wall temperature below the dew point of the inside air, while the air stream is still sufficient to deposit a lot of water. The custom of hanging pictures with the top of the frame away from the wall and the bottom touching increases the risk of condensed water reaching the picture, because it restricts convective air movement enough to allow the wall to become cold but not enough to prevent condensation.

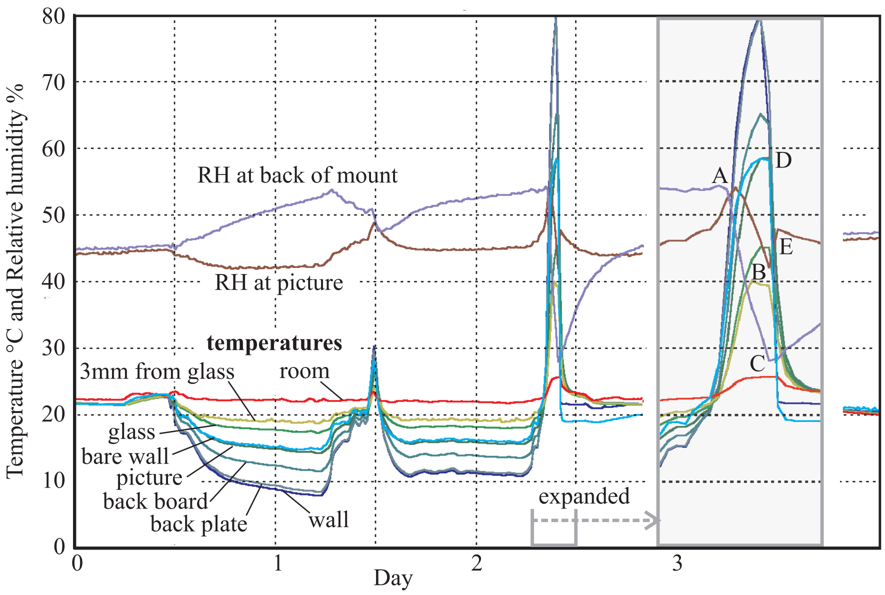

FIGURE 6. The microclimate in a picture frame mounted against a thin wall that cools at night and gets warm in the sun. On day 1 there was only weak sunshine, so the print warmed only a couple of degrees above the room temperature. There was nevertheless a considerable movement of water vapour from the back board to the print. When the wall cooled down the back board again acquired the higher RH. On day 2 the sun shone brightly. The temperature behind the picture rose to 80°C, while the open wall temperature was just 58° (point D). Water from the hot back board condensed on the inside of the glass and was sucked into the paper where it bulged towards the glass. The details are shown in the time stretched enlargement on the right: The RH at the back fell steeply from A to C. The RH at the picture rose at first to A but then fell to B as water condensed on the glass. When the picture was removed from the wall the RH at the print rose quickly to E, due to absorption of the evaporating dew on the glass, later the RH fell again as the back board absorbed water.

These arguments apply to humidified buildings, where the dew point of the room air is often above the outside temperature. All buildings are humidified to some extent, because all human activities release water vapour and none absorb it.

3.4. **Thermal insulation should not be used.** There seems to be no advantage in thermally insulating the back of the mount. An air gap between mount and wall is normally adequate to reduce the temperature gradient to insignificance. Sufficient insulation to materially reduce the temperature gradient through the picture would be so thick that it would be much uglier

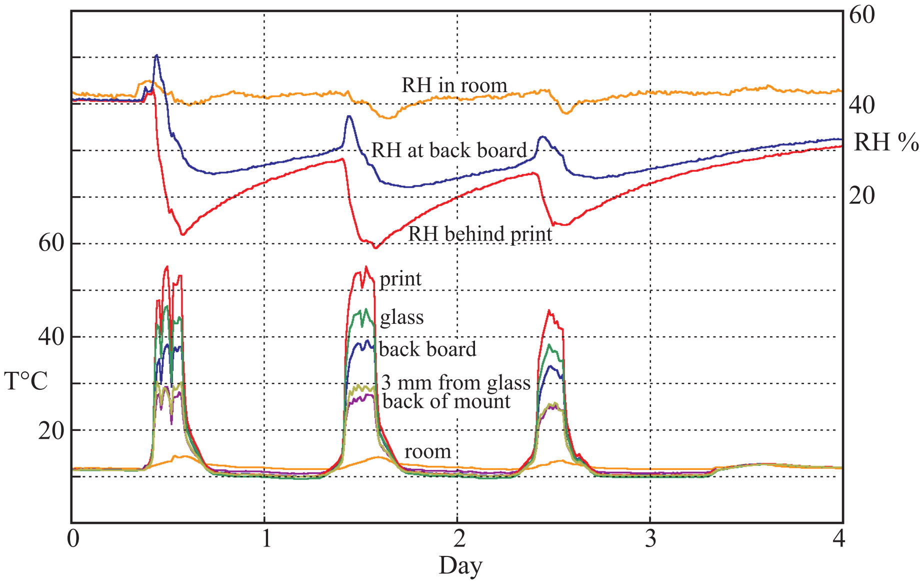

Figure 7. Temperature and relative humidity in a framed print exposed to sunlight through a double glazed window. The RH directly behind the print fell abruptly during the period of exposure. The RH at the back of the mount rose at first, fed by moisture released by the print. After that the RH fell at both measuring points. This was because the print is dark. The coolest part of the enclosure was the white mat and the outer edge of the back board. The moisture accumulated there and returned only slowly when the sun moved off the picture.

than an air gap. It will also increase the likelihood of condensation on the wall. Insulation behind the picture is dangerous when sun shines on the picture, because the back board will heat up. Condensation will then occur on the glass, which will be the coolest part of the assembly.

3.5. **Non-absorbent mounting materials are not usually beneficial.** If the print is the only water absorbent material in the enclosure, there will be much less condensation when the temperature at the back, or at the glass, drops below the dewpoint of the air within the enclosure. On the other hand there will be no buffer for the condensate that does form, so staining of the picture is still possible.

The change in water content of the print will always be greater when the backing material is absorbent, because a lot of water will move into the backing material even at temperatures above the dew point. However, an absorbent mat is such an advantage in maintaining a constant water content in periods of uniform temperature that it is more sensible to ensure a uniform temperature than to experiment with non-absorbent materials and enclosures.

4. Conclusions

Sealing the back of a picture framed behind glass is a good idea. An entirely airtight enclosure is even better, if the picture is to be exposed in a climate with seasonal extremes that would encourage biological attack. The only argument against this practice is that it seals in pollutants released within the enclosure. Careful choice of materials and sealing of wooden frames with aluminium foil can eliminate this danger.

The temperature gradient caused by a cold or warm outer wall can be made innocuously small by separating the picture from the wall by about 20 mm for a small picture, more for a large picture. Insulation behind a picture gives no benefit and is not recommended.

Use of non-absorbent mounting materials reduces RH variation at the picture when a temperature gradient arises and reduces the volume of condensate when an extreme temperature gradient arises. Absorbent mats, however, are good at buffering seasonal change in ambient RH. It is usually easier to reduce temperature gradients than seasonal climate change, so an absorbent mat is generally better.

5. Note and Reference

The microclimate data were collected by a Campbell Scientific CR10X data logger. The temperature sensors were type K thermocouples. The RH was measured with Honeywell HIH3605B capacitive sensors. Technical details of the experimental methods can be obtained from Tim Padfield.

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