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Wadum, J.

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The Structural Conservation of Panel Paintings
The Structural Conservation of Panel Paintings

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THE GETTY CONSERVATION INSTITUTE
LOS ANGELES
The Abduction of Proserpine, 1570. Detail. Oil on panel, 228.5 x 318 cm. The J. Paul Getty Museum (73.PB.73), Los Angeles.

Back cover and page 305: Girolamo di Benvenuto, Nativity, ca. 1500, reverse. Tempera on panel, 204 x 161 cm. The J. Paul Getty Museum (54.PB.10), Los Angeles. The panel bears witness to the history of its conservation: This light, modern cradle was installed in 1987, after the removal of heavy, traditional crossbars (see page 187), traces of which are still evident. Strips of aged poplar, inserted to repair cracks caused by earlier restorations, can also be seen.

Page 1: Transverse surfaces of chestnut (Castanea sp.) (left) and poplar (Populus sp.) (right), showing pore structures.


Page 187: Girolamo di Benvenuto, Nativity, reverse. A cumbersome, traditional cradle, installed around 1900 and removed in 1987, is shown.

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Microclimate Boxes for Panel Paintings

Jørgen Wadum

Probably there is no construction that suffers more seriously as a result of the movement of wood than the paint on a painted panel.

—R. D. Buck, 1952

In a poorly climatized museum or during transit, it is crucial to control continuously the moisture content of humidity-sensitive objects such as wood, fabric, and paper.

The use of microclimate boxes to protect vulnerable panel paintings is, therefore, not a new phenomenon of the past two or three decades. Rather, it has been a concern for conservators and curators to protect these objects of art at home and in transit since the end of the nineteenth century. The increased number of traveling exhibitions in recent years has heightened the need to protect paintings during circulation (Thomson 1961; Mecklenburg 1991).

Departures from the usual climatological surroundings may cause swelling or shrinkage of a panel, resulting in cracks, splits, and cleavage of the support or between the support and image layers (Stolow 1967). Early research in packing has covered some aspects that are used as criteria for the microclimate boxes (Stolow 1965, 1966, 1967). Although there may not be an "ideal" relative humidity (RH) for museums, it is evident that some objects require, or would benefit from, separate microenvironments, regardless of the chosen RH set point (Erhard and Mecklenburg 1994).

The use and design of microclimate boxes have been evolving since 1892. These boxes may be divided into three broad groups: those using an active buffer material to stabilise the internal RH, a more recent box containing no added buffer material, and, in recent times, boxes with an altered gas content. Another concern is the appearance (aesthetics) of the box.

The cross-grain instability of wood has been a perennial problem to artisans as it is in the nature of wood and wooden objects to seek an equilibrium between internal moisture content and that of the surrounding atmosphere (Fig. 1a, b) (Buck 1961). Examination of the hygroscopic behavior of various wood species shows that green as well as old wood responds to changes in humidity (Buck 1952, 1962). The swelling and shrinkage of two panels was

Wood as a Hygroscopic Material

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Correlation between RH, temperature (°C), and grams of water per kilogram (g/kg) in (a) air and (b) wood.

Figure 1a, b

measured with strain gauges and recorded. The investigation showed that the movements of a new oak panel and a panel from the seventeenth century were analogous (Klein and Bröker 1990).

Experiments with beech (hardwood) and Scotch pine (softwood) demonstrated that the hardwood has a slightly higher moisture change rate than the softwood, and that the movement of beech samples was therefore larger than that of the Scotch pine samples (Stevens 1961).

The ratio of the area of exposed surface to the volume of the wood also influences the reactivity of the wood. Thin pieces of wood respond more quickly than thick ones, while small pieces respond more quickly than large pieces of equal thickness. When a panel is thinned, as is often done during the cradling process, the ratio of exposed surface to wood is sharply increased; therefore, the diffusion of moisture throughout the bulk of the panel and the response to changes in the atmospheric environment are accordingly accelerated.

It has also been demonstrated that the higher the temperature, the more rapid the rate of moisture transfer. A piece of wood comes to equilibrium about twice as fast at 24 °C as at 12 °C because the vapor pressure of water at 24 °C is twice as great as at 12 °C, if the RH is constant.

Finally, the greater the change in RH, the faster the rate of moisture transfer (Buck 1961, 1979).

The preparation of a panel before the painting process must also be considered (for a discussion of historical techniques, see Wadum, "Historical Overview of Panel-Making Techniques," herein). The size and ground may contain hygroscopic materials, such as glue, that also react to changes in RH and temperature. The behavior of a number of materials found in traditional paintings has been analyzed under the stress of temperature fluctuations and varying RH (Buck 1972; Mecklenburg and Tumosa 1991). Another important result of climatological fluctuations is the changing stiffness of painting materials and mediums in traditional paintings (Michalski 1991).

Changes in RH produce measurable changes in the dimensions of a panel. Research has also shown that paintings change dimensionally as a consequence of temperature, independent of a change in RH (Richard 1991). However, bearing in mind that the thermal expansion of a panel enclosed in a case is small, the conservator should concentrate on keeping the moisture content of the wood constant and thus ensure dimensional stability of the panel. The unanimous advice given by various authors
Microclimate boxes for panel paintings holds that a narrow range of temperature and RH change is advisable for the preservation of a panel painting.

Thomson's studies on the different properties related to RH variation with temperature in cases containing wood set the standards for the field (Thomson 1964).

Calculations show that equilibrium moisture content (EMC) is more relevant than RH, since in the microclimate box, the ratio of wood to air will exceed 1 kg of wood per 100 l of air, a ratio that is critical to controlling the humidity of the wood. Stolow, in particular, provided much useful information and experimental data on tests on enclosed packing cases (Stolow 1965). Tholow, Thomson, and Padfield were primarily interested in stabilizing RH at a constant temperature (Thomson 1964, 1977; Padfield 1966; Hackney 1987). Apart from Thomson's calculations and experiments showing the RH and temperature changes within cases, as well as the relationships between them, Padfield's contribution to the understanding of the phenomena inside small closed areas must be regarded as part of the standard literature.

If much wood is present, its moisture content determines the RH of the entire volume of the microclimate box. It has been emphasized that the diffusion of water vapor through the case materials and through stagnant air in gaps should be kept in mind when a hermetically sealed case is created (Padfield 1966; Brimblecombe and Ramer 1983). Padfield remarks that water vapor diffuses through air almost twice as fast as oxygen and nitrogen and very much faster than dust particles.

Objections have been raised about the exhibition of objects in almost closed containers, because of the danger of condensation forming on the glass or object when the temperature suddenly falls. However, Padfield's calculations and experiments confirmed that the stabilizing effect of absorbent materials, such as the wooden panel itself, prevents condensation. Padfield concludes that the conservation of wooden objects in rooms that are heated but not air-conditioned often demands an artificially raised RH in individual showcases. To this end, he recommends using saturated salt or a solution of sodium bromide to stabilize the RH of a showcase.

Toishi describes the common belief that a closed package containing a large quantity of wood dries out when the temperature is raised, even though the wood gives off moisture to balance the dryness of the air. He counters, however, that the quantity of moisture vapor released from the wood when temperature rises is generally so great that it increases the RH (Toishi 1961).

Stolow describes the relationship between EMC and RH, as well as the variations in RH and temperature in sealed cases containing wood. A case at 20 °C with an initial RH of 50% will increase to 53.5% RH when the temperature is increased to 30 °C. If, on the contrary, the temperature were lowered to 10 °C, the final RH would be 46.5%. If the case were not sealed or the air volume were very large, however, he recommends that the internal RH be stabilized with silica gel (Stolow 1967).

To this end, Weintraub tested five different types of silica gel (Weintraub 1981; Stolow 1967). The tests showed no direct relationship between the actual moisture content of a particular sorbent and its relative ability to control the RH of a showcase.
Miura examined sorbents for their static and dynamic characteristics, to estimate their ability to buffer RH changes in a showcase (Miura 1981).

Wood heated to 30 °C lost 2% of its moisture content, which the silica gel or Art-Sorb could easily absorb in order to maintain the RH at stable values (Hackett 1987; Kamba 1993; Wadum et al. 1994).

"Sealing a show-case to prevent diffusion and convection and to resist, or deform under, pressure changes up to 0.5 mb would very much reduce the leakage of air and be a major contribution to the conservation of a wide variety of art objects," Padfield wrote in 1966. This concept, as shall be seen, has been a concern since the end of the nineteenth century.

In deciding the ways and means of creating a microclimate, the conservator should consider the following questions (Cassar 1984, 1985):

- What are the requirements of the object, based on its environmental history?
- What is the climate in the gallery where the microclimate case is to be placed?
- What are the functions of the microclimate? Is it to act as a stabilizing, dehumidifying, or humidifying factor to the object?
- What will be the materials used for constructing the display case?

The importance of using inorganic materials, such as glass and metal, in constructing the case cannot be emphasized enough (Padfield, Erhard, and Hopwood 1982). However, the buffering material can be either organic (wood, paper, textiles) or synthetic or natural derivatives (Nikka pellets, Kaken Gel, zeolite clay, silica gel, Art-Sorb) (Weintraub 1982). Thomson’s recommendation of 20 kg of silica gel per cubic meter for buffering purposes in exhibition cases has been regarded as a good starting point (Thomson 1977), but in certain circumstances, the same result may be achieved with less. Recent research, however, questions the recommendation of using any buffering material at all in microclimate boxes (Wadum et al. 1994).

Display materials also influence the buffering ability of a display case and should therefore be chosen carefully. They should all be conditioned before installation. Conditioning hygroscopic materials may require up to one month’s exposure to the desired RH before the equilibrium wished in the microclimate environment is achieved (Fig. 2a–c).

**Microclimate boxes with added buffers**

Even though most authors thought that wood itself could be used as a buffer, there was often a tendency to add an extra buffer to stabilize the internal RH of the microclimate box.

In 1933 a patent appeared for the use of salt-hydrate pairs as regulating substances in cases and picture frames. The humidity should be controlled through a low rate of air exchange, so that all the entering air passes over certain salt-hydrate pairs. In this way, one salt may absorb moisture from air that is too humid, while the other salt will conversely release moisture if the air is too dry (Wilson and Barridge 1933). Shortly thereafter, in...
1934, MacIntyre published test results to show that RH in a poorly sealed display case is still more stable than the RH in the surrounding room. He further demonstrated that the hygroscopic panel, frame, and fabric lining of the case would improve this stability so that even with a 1 mm gap around the glass base, a fairly constant RH could be maintained during the week of monitoring (MacIntyre 1934). The results were applied to an air-conditioning system for Mantegna’s cartoons at Hampton Court Palace.

In 1934 Constable proposed an alternative to buffers. The idea was to feed conditioned air into the frame (or case) by means of pipes, however, this was dismissed at the time on the presumptions of bulk and inconvenience (Constable 1934). The idea was nevertheless put into practice approximately fifty years later (Lafontaine and Michalski 1984). In 1936 Curister enclosed a panel painting attributed to Hugo van der Goes. Salts were kept in trays within the base of the double-glazed standing vitrine, which was capable of keeping a stable RH indefinitely, provided the exchange rate with the exterior was not too great. Small glazed openings were made at the top of the cases, through which enclosed hygrometers could be monitored. Before the construction and assembly of the microclimate box, the wood used in the construction of the cases and frames was carefully seasoned and conditioned in an atmosphere of the agreed moisture content. During the most difficult climatological months, the sealed cases showed a stable internal RH of 55%.

More than twenty-five years would pass before a new description of a microclimate box for a panel painting appeared (Sack 1963–64). Sack describes how a controlled environment was made for a panel painting and kept stable during a low winter RH of 12–28%. A large sealed wooden case with a double glass door was constructed that held pans containing a saturated solution of magnesium nitrate hexahydrate. A small fan distributed the conditioned air to all areas within the case. In this manner, the RH was held stable between 50% and 52%.

Shortly after, Stolow published his aforementioned studies of the humidity and thermal properties of a sealed case (Stolow 1967). If the elements (case and painting) are in equilibrium with the environmental RH and temperature when the case is sealed and then subsequently placed in another environment, a new equilibrium will
develop within the case after a certain time. Thus the sealed case—when tightly packed with conditioned wood and similar hygroscopic or moisture-sensitive components—can maintain reasonable RH control over temperature changes.

There are two instances to which the above conditions do not apply and where more complicated formulas must be used. The first arises if the case is not tightly packed; the second occurs when the internal air volume is relatively large compared with that of the humidity-sensitive materials. If the air volume is very large, the moisture properties of the internal air dominate the relationship between RH and temperature; in this case an increase of temperature will cause a decrease of the RH, and vice versa. Stolow advises that silica gel be used to stabilize the RH, as the response of the gel to temperature is negligible.

Based on the studies of Thomson and Stolow, Diamond's 1974 article on a "micro-microclimate" gave the first description of a microclimate box for a panel painting on display. A sixteenth-century French portrait from the school of François Clouet was placed in a showcase. It appeared that with a maximum fluctuation of temperature in the galleries of 11 °C, the RH should vary by less than 4%.

Accordingly, a hardwood box was constructed and fitted at the front with glass, which was puttyed to make an airtight seal. A chipboard back was made. This procedure yielded a box of approximately 13.7 l volume, containing about 220 g of wood (picture and frame), which, according to Thomson's figures, should have produced a near-stable environment. The wood of the case was left uncoated so that it could play its part in absorbing and giving off moisture. The whole box was conditioned for two weeks to 55% RH (±5%) and 20 °C (±2 °C).

The fact that the picture showed signs of distress very soon after being treated suggested either that it was sensitive to changes of RH of less than 4% or that the design of the box was faulty.

The construction of a completely airtight box was impossible, due to finances. Therefore, a buffer was chosen to reduce the RH fluctuations. The principles involved were those laid out by Stolow (1966). The box was fitted with panels of silica gel held in a grid. The grid was crucial, as it spread the silica gel over the largest area possible within the box. The open box and all its materials were left for four weeks to reach equilibrium in a stable environment.

The environment was controlled with a small hygrometer and was stable around 41% RH (±4%) over two months. Variations inside the box were no greater than 5%, so the box was considered a safe container for the painting.

The box protected the painting from considerable fluctuations of approximately 20% during this period. Thus, only minor changes in RH took place inside.

The same year Toishi and Miura described how the Mona Lisa from the Louvre was exhibited for fifty days in the Tokyo National Museum (Toishi and Miura 1977). Throughout the run of that exhibition, the painting was enclosed in an iron case equipped with a double-panel glass window and lined with a 75 mm layer of glass. To maintain a stable RH of 50%, zeolite was placed in the case. The zeolite was found to be capable of absorbing various gases such as sulfur dioxide, hydrogen sulfide, ammonia, carbon dioxide, and formaldehyde. The zeolite had been brought to a humidity equilibrium in air at 60% RH (Kenjo and Toishi 1975).
Probably the most-cited contribution on controlling microclimates was written by Thomson in 1977. He derived a formula with experimental support to predict the RH changes inside an unsealed exhibition case that contained a buffer such as silica gel. The formula showed that a well-constructed case (containing about 20 kg silica gel per cubic meter of case volume) should constrain seasonal humidity variation within reasonable limits and, in some climates, make air-conditioning unnecessary. The practical solution recommended by Thomson was to make a showcase of non-moisture-permeable materials and snugly fitting closures, possibly gaskets.

For RH conditions above 50%, silica gel offers little advantage over wood, as its $M$ value is about the same. However, at lower RH values silica gel is the best buffer.

In this article Thomson does not take fully into account the change of temperature; his focus is mainly on the RH changes. Tests of the half-time of the case were made under constant temperature levels. Also, the tests were conducted only with silica gel, not with other buffer materials, such as wood.

The leakage rate for the case is important. Thomson refers to important studies by Padfield on the problem of diffusion through various materials (Padfield 1966). Sack and Stolow (1978) reported that in a case designed in 1963 to exhibit a German panel painting in the Brooklyn Museum’s main entrance lobby (an area of the museum with a particularly erratic climate), a saturated solution of magnesium nitrate hexahydrate proved to be effective in controlling the RH at 50–52%.

In another situation, a similar box served to control the microclimate around a painting on a thin wooden panel. This microclimate box was constructed to protect a fine Fayum panel on loan to the Brooklyn Museum. The intention was to design a case as airtight as possible to preserve the required level of RH, independent of external variations. The Fayum painting (44.5 x 28.5 x 0.2 cm thick) was painted on thin wood. The wood had been bent to conform to the double convex contours of the original mummy case.

It was decided to enclose the Fayum painting in a case kept at a constant RH of 50%. Preconditioned silica gel would serve as the RH stabilizing agent in the case. The case consisted of an outer display box and an inner, airtight, metal-and-glass chamber. Inside the case, a wooden frame was covered with fabric containing the preconditioned (50% RH) silica gel, with the painting secured 4 mm in front of the silica gel panel. A section of paper-strip RH indicator was placed in the corner of the case to allow continuous monitoring of the internal RH. The painting flattened considerably from its convex warp while sealed inside this case.

Although the case was almost airtight, a very slow moisture exchange with the exterior could still occur over time. This possibility made it necessary to recondition the silica gel annually. Since it was time-consuming to remove, recondition, and replace the silica gel, a second panel was made. Kept under secure airtight conditions, it could be installed as a replacement to the "worn-out" panel, which would be reconditioned and readied for the next annual replacement.

Acclimatization of two large (922 l) vitrines of air containing five icons was carried out to attempt the difficult task of stabilizing the gallery environment at 50–60% RH (Schweizer and Rinuy 1980). To keep the environment stable, the recommended amount (20 kg m⁻²) of silica gel was
placed in a honeycomb tray and covered with a nylon screen. With the screen facing the interior, the tray formed the back of the case. The results showed that the temperatures in the gallery and showcase were approximately the same at all times. In contrast, the RH within the cases remained stable despite changes of 44–74% in the RH outside the showcases. Evaluation of the amount of silica gel actually required to keep the RH level stable in the vitrine led to a recommendation of 10–15 kg m\(^{-3}\)—almost half of what Thomson advised. It was also noted that the conditioning of the silica gel should be at an RH value 5% higher than what was actually desired in the case.

At the Sainsbury Centre for Visual Arts at Norwich, England, the use of a mechanical system dependent on electricity was considered impractical to assess RH control employed within showcases (Brimblecombe and Ramer 1983). The use of a saturated salt solution, which is most effective when auxiliary support is provided by an electric fan, presented the same drawbacks as the fully mechanical system. The use of silica gel enabled the creation of a self-sufficient system without the need for electrical support.

To monitor the mechanism of air exchange between the interior and the exterior of the case, an experiment was designed using a tracer-gas method to monitor the concentration of various gases over time within a standard-sized display case. Padfield's indication that the air-exchange process occurs essentially by diffusion was confirmed (Padfield 1966). Additionally, Thomson's studies showing that the exchange of air within a display case—and hence water-vapor variation—occurs exponentially were also verified (Ramer 1981, 1985).

The conclusion reached, based on a calculation of the hygroscopic half-time, was that Thomson's recommendation to use 20 kg m\(^{-3}\) of silica gel was valid.

The diffusion of air is the primary cause of RH variation within showcases; therefore, good construction of cases is essential (Ramer 1981, 1985).

Also in 1981, a number of case histories about controlled-climate cases were presented by Stolow (1981). One such case involved a large panel painting and its predella by Neri di Bicci. The acrylic case enclosing the panel was relatively small in air volume compared to the object volume, having only slightly larger dimensions than the artwork to allow for maximum buffering action of the silica gel. The estimated weight of the panel and the predella was 250 kg. After consideration of the panel painting and the supporting materials (i.e., fabrics, wood), it was deemed necessary to place inside the case approximately 200 kg of conditioned silica gel, which was held in place by a screened panel covered with linen fabric.

With the past environment of the panel painting considered, it was decided to establish a slightly higher-than-average RH (45%) within the case. The EMC of the silica gel was periodically tested during the conditioning procedure to verify, via sorption curves (isotherms), that the 45% RH operating level had been reached.

Electronic probes were considered to monitor the interior of the case, but because they are costly and require frequent calibration, they were abandoned in favor of paper RH indicators. After one year of operation, it was shown that the internal RH level had been kept at a fairly constant 40–43% RH, despite wide variations in the gallery climate.

A further example of a specific microclimate box is to be found in a description by Knight of the Tate panels in the Church of All Hallows.
Berkyngechirche by the Tower (Knight 1983). A box was made of Perspex (known in the United States by the trade name Plexiglas), with a sheet of aluminum as a backing board. Steel brackets attached the box to the wall, thus leaving an air gap between the back plate and the wall.

Recommendations by Stolow and by Sack and Stolow provided the basis for the humidity-control requirements of the box (Stolow 1977; Sack and Stolow 1978). Silica gel was placed in the box in small narrow trays that could be individually removed for reconditioning. After installation, a small hygrometer showed that the interior RH was maintained at a level of 56-58%.

The variation in RH in an experimental exhibition case that was intentionally not sealed or airtight was monitored over two years (Schweizer 1984). The RH of the surrounding room varied considerably (20-70%), but the RH inside the case, which contained silica gel, maintained acceptable stability (40-58%). This type of box, therefore, would prove very useful in regions with hot summers and cold winters. The amount of silica gel required was based on Thomson's formula of 20 kg m⁻³.

Also in 1984, a microclimate box was presented by Ramer for a seventeenth-century panel painting from the Netherlands (Ramer 1984). The goal was to create—with a more aesthetic design than previous microclimate boxes—a humidity-controlled display case for the painting that covered both the panel and frame. The new microclimate box was to be fitted into the extended rabbet of the picture frame, making this the first occurrence of its kind since the late nineteenth century (Simpson 1893) (see the section below entitled "Microclimate boxes that alter the gaseous content").

Practical requirements demanded a low maintenance level and easy recharging of the silica gel humidity buffer. The RH requirement within the case was 55%. The silica gel amount was determined according to Thomson's formula of 20 kg m⁻³.

The microclimate box was made of inert materials (e.g., aluminum), and the glazing at the front was composed of 5 mm polycarbonate sheeting (Lexan). As in previous designs, the tray of silica gel could easily be remounted and reconditioned. The box was designed by B. Hartley, A. Southall, and B. L. Ramer.

Thirteen Fayum mummy portraits and a panel painting of Saint Luke by Simone Martini, all housed in the J. Paul Getty Museum in Malibu, California, were placed in special cases that had a higher humidity than normally maintained in the paintings galleries (Rothe and Metro 1985). An absolutely airtight microclimate box was constructed, with care taken to make sure that it wasn’t too visually overpowering. The case consisted of three basic sections: a back panel, a front honner (vitrine), and a silica gel container. Art-Sorb was selected as the buffer in accordance with comparative performance statistics published by Weintraub and Miura (Weintraub 1982; Miura 1981).

For the Simone Martini panel, 4 kg (dry weight) of Art-Sorb was placed in the gel container and conditioned in a humidity chamber to 66% RH. This amount is four times greater than recommended by Thomson (1977) for a case of this size. The showcase had been on display since March 1983 in a temperature- and RH-controlled gallery. The RH in the gallery was always 14-16% lower than the RH inside the case.

The same construction was used for the Fayum portraits, except for the back panel, which was replaced by a Formica panel. The silica gel con-
tainer was made out of birch with a silk-screen fabric stretched over the front and back. The gallery used for this display is open to the outside environment during public hours, a factor that influenced the RH, which ranged from a low of 37% to a high of 68% during the test period. During the year, the temperature ranged from 20 °C to 27 °C. The mummy portraits required cases that were capable of maintaining an ideal environment of 50% RH, with minimal or no fluctuations. After observation of the hygrometers in the cases, it was ascertained that the RH never varied more than 2%. Thus, it was not necessary to recondition the Art-Sorb for two years. Because the cases were constructed of Plexiglas, the objects were clearly visible and could be lit from the outside without any apparent change in temperature.

Dissatisfaction with the microclimate boxes previously used by the Kunsthistorisches Museum, Vienna, led Ranacher (1988) to present a slightly different idea. In his concept, silica gel could be renewed without dismantling of the box, and an electronic device enabled convenient external checking of the internal environment (Mayer 1988). The back and sides of the box were made of wood to aid in stabilizing the internal moisture content. The front of the box consisted of a Plexiglas hood, which was mounted on the frame of the backing board. The frame of the painting on display would be mounted over a hole in an internal wooden board covering the backing of silica gel. The amount of buffer material (7 kg m⁻³) was determined by Ranacher’s own experimentation, not chosen according to previously recommended high values of 10-20 kg m⁻³, or recommended low values of 1-2 kg m⁻³ as recorded by Miura in his laboratory tests (Miura 1981). The ratio used in Vienna had previously been proved adequate for maintaining a stable RH of 50% within a microclimate box that hung in a gallery having temperature fluctuations of 14-23 °C. The built-in electronic device for monitoring RH and temperature levels was invisible to the public. Personnel could read the electronic data by plugging in a wire at the bottom edge of the box.

At the United Kingdom Institute for Conservation conference, Cassar and Edmunds individually presented microclimate boxes designed to fit within the frame of the painting, similar to those presented by Ramer in 1984 (Cassar 1988; Edmunds 1988). Cassar enclosed a panel painting in a buildup of the original frame, which permitted the manufacture of a glazing (Perspex) and backing. The environment of the box was kept at a stable RH through the presence of an Art-Sorb sheet placed behind the painting. Edmunds constructed a closed box with low-reflection glass at the front and with Perspex sides and backing. A Perspex grid containing conditioned silica gel crystals in small sacks could be stored behind the panel painting. A hair hygrometer and, later, Grant Squirrel Data Loggers were used to monitor the box interior and surrounding environment. The data showed that the inside RH remained stable for a considerable period at various ambient conditions without recalibration of the silica gel. Cassar also reached the same conclusion.

Bosshard and Richard also recognized the disadvantages of microclimate boxes that enclosed both the painting and its frame (Bosshard and Richard 1989). A box enclosing only the painting was developed and widely distributed by Johnson and Wight in the beginning of the 1980s in California. This box was further refined, in conjunction with an empirical trial with the Thyssen-Bornemisza Collection, to become a standard-climate vitrine. This new microclimate box was flat and could, therefore, be fitted
into the frame of the painting (Bosshard 1990). With low-reflection glazing, the box could hardly be seen. The rabbet of the frame often had to be extended to make room for the box, but in situations where this action was not desirable, the sides of the vitrine could be made of a thinner metal foil instead.

Art-Sorb granules were preferred to Art-Sorb sheets, as the gel is more reactive in absorbing and desorbing moisture. The inside of the box was made according to the specifications: one-third panel, one-third silica gel, and one-third air.

Because RH always drops after the box is closed, the Art-Sorb was conditioned to a RH of 3% higher than desired. A paper RH meter was placed in back, making it possible to check the RH inside the box at any time. Foam rubber on the silica gel frame pressed the painting forward to the front of the box. At present, more than fifty-eight panel paintings—on loan or in the Thyssen-Bornemisza Collection—are kept in these vitrines.

Simultaneously with the empirical trial in the Thyssen-Bornemisza Collection, Mervin Richard carried out lab tests at the National Gallery in Washington (Richard 1993). The results showed that the thicker the walls of the box, the greater its stability. The interior RH depends on the amount of the buffer material, and the greater the difference between RH outside and inside the case, the quicker the inside will change to a new equilibrium.

Thomson recommended 20 kg m⁻³ of silica gel. As the Art-Sorb in this case was deliberately over the requirements of the air volume, “overkill” was established. Richard proved with his climate chamber that a temperature change of 10 °C resulted in a change of about 2% RH inside the box, depending on its size and capacity to absorb the temperature change.²⁶

In 1990 a microclimate box to be fitted within a frame was constructed in the Mauritshuis, The Hague, largely following the concepts of Ramer, Bosshard, and Edmunds (Wadum 1992).²⁷ The glazing was, however, always a layered safety glass that enabled the box to travel with minimum risk.²⁸ At first the box included silica gel or Art-Sorb sheets to stabilize its internal RH during display and transit (Wadum 1993).²⁹ Between the glazing and the front of the painting, in the rabbet, a grid was placed along all four sides allowing convection of the air from front to back and vice versa.

Small built-in microprocessor loggers monitored the RH and temperature from the time of installation until the painting was returned after loan.³⁰ The printout showed that the RH stayed stable within 2%, despite temperature fluctuations of more than 10 °C.

Simultaneously with the Mauritshuis, the Rijksmuseum in Amsterdam was also developing a microclimate box. This box, a low-budget variant, was initiated and constructed by Sozzani, who needed a simple, easy-to-mount box to fit into the frame (Sozzani 1992). The box was constructed of safety glass that was mounted and sealed in the rabbet of the frame. Behind this, the painting was mounted in the usual way. Thin wooden battens were built up on the back of the frame, allowing enough depth in the rabbet for the insertion of a sheet of Art-Sorb behind the panel. The stainless steel backing sealed off the box with airtight gaskets.

The primary advantage of this type of box is that the rabbet never has to be extended, a requirement that would be undesirable in many situations. The previously used microclimate boxes from California required
some manipulation of the frame.\textsuperscript{31} The Rijksmuseum boxes also proved effective when monitored with humidity indicator strips or small hygrometers, all of which indicated a stable RH within the boxes in the museum environment.

Extensive studies undertaken by Richard have confirmed that temperature changes affect panel paintings much faster than do RH variations (Richard 1994). Although he concludes that silica gel has no effect on the temperature changes, he nevertheless recommends that the gel remain in use for microclimate boxes. Drawing on the assumption that virtually all microclimate boxes leak, Richard states that silica gel plays an important role in stabilizing the RH in display cases used in unsuitable environments for extended periods.

**Microclimate boxes without added buffers**

A more recent approach to the construction of microclimate boxes relied on the hygroscopic behavior of the wood panel itself as a stabilizing factor within a small volume of air. Such boxes were not kept at a stable RH through added buffers but instead maintained their own internal moisture equilibrium at changing temperatures.

A critical approach to the consistently recommended use of a moisture buffer in small display cases was presented by Ashley-Smith and Moncrieff (1984). Their experiences in the Victoria and Albert Museum in London showed that the silica gel in a showcase neutralizes the short-term RH fluctuations but does not compensate for seasonal changes. Ashley-Smith and Moncrieff concluded that for wooden showcases, silica gel gives poor results in relation to the time and expense required to purchase, prepare, and handle it, as well as to design and build showcases to accommodate it. They stated that an ordinary showcase without silica gel fares nearly as well—or as poorly—in reducing short-range fluctuations. The same conclusions were drawn in reference to some old-fashioned walnut cases in the Royal Ontario Museum, Toronto, that proved remarkably effective in slowing moderate fluctuations of RH (Phillimore 1979). For best results, a well-sealed case made completely of metal and glass or plastic is usually essential (Brimblecombe and Ramer 1983). However, for the Victoria and Albert Museum, wooden case vitrines serve in themselves as useful, additional buffers (see Cassar and Martin 1994).

Also in the early 1980s a special type of microclimate box was created by Padfield, Burke, and Erhard (1984). A cool-temperature display case was made for a vellum document placed in a close-fitting airtight container. The document required a stable temperature of $16.16 \degree C$, some six degrees cooler than the gallery, and an RH of 40–50%. The box maintained a nearly constant RH after cooling; however, special care was necessary to minimize temperature gradients. The case performed satisfactorily for one year with no change in internal moisture content.

The simplest method possible was chosen for displaying this document. It was sealed inside a thin, airtight container that was cooled by means of the Peltier effect.\textsuperscript{32} The refrigeration system of the box consisted of two coolers at the bottom of the aluminum tray holding the microclimate box.

A close-fitting, airtight enclosure has many advantages for the temporary exhibition of flat pieces of vellum or paper. It can be designed to maintain a nearly constant moisture content and a safe RH. At room
temperature, paper contains thousands of times more water than an equal volume of air does. In a sealed box full of paper, therefore, it is the paper that controls the RH of the surrounding air, if both are of the same temperature.

Based on the psychrometric chart, it was obvious that a container holding more than 1 g of paper per liter of air has a reasonably stable RH as the temperature varies (a rule of thumb that, incidentally, holds true over the whole range of ambient temperature). This conclusion applies only to a slow temperature change imposed uniformly to the paper and box.

It is important to remember that absorbent material such as paper or silica gel only functions as an RH buffer if it is at the same temperature as the air or object to be buffered. To buffer for eventual air leakage of the sealed box, extra paper was enclosed in the box to increase the buffering capacity.

Apart from using inert material for the inside of the box, a further precaution against air pollution involved using paper containing calcium carbonate to absorb acid gases.

In 1987 Hackney warned against enclosing buffering materials such as silica gel in small, sealed environments. He underlined, as have authors before him, that the equilibrium of silica gel or similar buffers is not dependent on changes in temperature (Stolow 1965, 1967; Thomson 1964, 1977; Weintraub 1982). On the contrary, hygroscopic materials such as wood were characterized by relative equilibrium, showing a higher RH at higher temperatures, and vice versa.

Despite these developments, the creation of microclimate boxes continued with added buffers such as silica gel or Art-Sorb (as discussed above in the section entitled "Microclimate boxes with added buffers"). The tradition continued, under the influences of guidelines laid out by the authors mentioned above, to keep the internal RH stable under all circumstances.

Richard reported in 1991 that in closed cases, falling RH levels caused by temperature decreases should not cause alarm, noting that several publications have emphasized that it is not beneficial to maintain stable RH levels for hygroscopic works in transport if temperature changes are anticipated at the new location. If, for example, a painting were moved from 50% RH and 20 °C into a very cold gallery, a lower RH must be maintained if the EMC is to be kept constant within the object.

Users of microclimate boxes seemed fairly reassured by the stable RH values produced through the use of added buffers such as silica gel or Art-Sorb. However, considerations regarding the effects of temperature fluctuations on the wood of the enclosed panel developed into an extensive test program set up by the Mauritshuis, The Hague; the Central Research Laboratory for Objects of Art and Science (CL), Amsterdam; and the Rijksmuseum, Amsterdam (Wadum et al. 1994).

The tests at the CL demonstrated that buffering material should be avoided in small microclimate boxes. Otherwise, fluctuations in the temperature would initiate a breathing process between the non-temperature-reactive silica gel or Art-Sorb and the panel.

Boxes made of inert material proved effective in maintaining stable environments for the hygroscopic material inside. A box made of an inert front and back, but placed in the wooden rabbet of the frame, also provided effective maintenance against fluctuations of 10–30 °C. Long-term (i.e., more than eight hours) low or high temperatures were not
tested. RH fluctuated between 30% and 70% without any influence on the interior climate. The boxes were well sealed to prevent leakage.

The Mauritshuis microclimate box now uses polycarbonate sheets as a backing; because buffer material is not used, the reverse of the painting is left visible so that the courier or other museum staff can examine it without removing it from the microclimate box.13

Dimensional movement of different types of wood in closed cases, with and without silica gel, was studied by Kamba (1993). He states that the dimensional change of the wood inside the box without silica gel was less pronounced than that of the wood in the silica gel-buffered case. Kamba's studies thus confirmed the results from the tests at the CL, in which an equilibrium between wood and the surrounding air at different temperatures was attained without added buffers.

For these reasons the most recent microclimate boxes for panel paintings at the Mauritshuis and the Rijksmuseum are now made without any added sorbent material. The buffering role of the panel itself is regarded as sufficient for the small, enclosed environment of a microclimate box. However, care is taken to ensure stable temperatures around the microclimate box, whether it is on display in the gallery or in transport (Wadum et al. 1994). To this end, the research at the CL also showed that maintaining an open air space of 2 cm or more between the microclimate box and the wall increases considerably the stability of temperature within the box (see also Ranacher 1994). Thermally insulated transit crates may maintain a relatively stable temperature inside the microclimate box on long journeys (Fig. 3a–d).

Microclimate boxes that alter the gaseous content

Apart from one very early foray, the use of microclimate boxes with an altered gaseous content has become popular only in the last decade. This new interest arose from the need to reduce the deteriorating effects of oxygen.

The first known attempt to make a microclimate box was in 1892 in England by Simpson, to protect a painting by J. M. W. Turner in the Victoria and Albert Museum (Simpson 1893). The characteristics—tailored to fit the specific painting—of this sealed, airtight box were very similar to a modern microclimate box. Simpson’s box was even intended to be fitted into the original gilt frame and hung in the usual manner. The front was composed of glass; the back comprised glass, metal, or other materials. In Simpson’s box, nozzles were placed at the bottom for attachment to an exhaustor, which could extract air from the box to create a vacuum around the picture.
Simpson concludes his description by asserting that the color of the picture in the box would be hitherto immune to light, sun rays, dampness, or other damaging external influences. Indeed, time has shown that the Turner painting is in excellent condition to this day; until the present, the box has not been opened. Although hardly subject to vacuum for very long, Simpson’s box represents the first attempt to create an altered gaseous content around the object enclosed in the microenvironment.

The first inert gas display case was described by Byrne (1984). An effigy figure from Easter Island was placed in a round Plexiglas tube acting as a display case. The ends were sealed with Plexiglas disks fitted to the tube. Silicone rubber served as a gasket. The tube was 20 cm in diameter; its walls were 6.3 mm thick. To avoid the presence of water vapor around the effigy figure, the tube was charged with nitrogen gas to exclude oxygen and moisture. A modified aneroid barometer monitored the pressure within the case and confirmed the presence of a stable charge of nitrogen gas. Four years later the case showed a loss of pressure, so nitrogen gas was added again. A humidity indicator strip was placed in the case, and future recharging with nitrogen was accomplished by first bubbling the gas through a water bath.

The use of Ageless as a means of generating low-oxygen atmospheres for the treatment of insect-infested museum objects is discussed by Gilberg (1990). Ageless is a type of oxygen scavenger that is described by the manufacturer to be a mixture of finely divided moist iron, (ferrous) oxide, and potassium chloride, a combination that rapidly absorbs atmospheric oxygen. The oxygen concentration in a microclimate box can be reduced to less than 0.05% as the introduced Ageless quickly reacts with any oxygen leaks. Ageless can also reduce the oxygen concentration in a closed environment to less than 0.01% and can maintain this level indefinitely, depending on the permeability of the packing material.

Ageless is available in different package sizes that correspond to the amount of oxygen to be scavenged (for example, Ageless Z-200 is capable of absorbing the 200 ml of oxygen contained in 1 l of air). Ageless-Eye is an oxygen indicator in tablet form that changes color in relation to the absence or presence of oxygen. Tests in which insect-infested objects were kept at 30 °C and 60% RH resulted in convincingly stable, low oxygen levels and stable RH.

Ageless is being used to prevent deterioration of rubber, which becomes brittle as a result of ultraviolet light, ozone, and oxygen (Shashoua and Thomson 1991). After some rubber objects in the British Museum, London, were sealed in bags, the oxygen was reduced; an investigation into the deterioration rate of the objects showed positive results.

Further investigations on the uses and reactions of Ageless were undertaken at the Getty Conservation Institute to develop hermetically sealed, inert, gas-filled display and storage cases (Lambert, Daniel, and Preusser 1992).

No matter how well cases are designed and constructed, some air can always enter. If their value as oxygen-free chambers is to continue, the leaking cases must be flushed with nitrogen or some other inert gas. After the original flush, the oxygen-free life span of the case can be greatly extended by an oxygen scavenger placed in the case. Calculation of the approximate lifetime of a case is obtained by dividing the oxygen-absorbing capacity of Ageless in the case by the leak rate per day.
Measuring Devices

The Getty Conservation Institute studies were conducted on packets of Ageless-Z in boxes, in which RH-conditioned nitrogen was produced by control of the mixing ratio of dry nitrogen obtained from the cylinder, to humidified nitrogen—the result of dry nitrogen bubbling through water at room temperature (Byrne 1984). The test chamber was initially flushed with nitrogen until the oxygen reached the 1000–9000 ppm range. At this point Ageless was rapidly inserted and the test chamber hermetically sealed. The RH inside the chamber was maintained at 52% with saturated salt solutions (magnesium nitrate). This research showed that Ageless reacts rapidly and thoroughly with oxygen in a sealed case that is filled with an inert gas, and that has an optimal RH above about 50%.

Sealed cases filled with inert gas prevent the oxidation of the objects placed therein. In small flexible containers with little air content, Ageless can perform well in spite of slight warming. It is hazardous, however, to place Ageless in a large rigid case containing air because of the heat produced and also because of the risk of implosion when the oxygen (20% of air) is removed. A sealed case filled with an inert gas should have flexible bellows attached, to compensate for temperature and pressure fluctuations in the museum atmosphere.

A slight color change in cinnabar, litharge, and sienna has been observed on objects in nitrogen-filled sealed cases (Toshiko 1980). There is good evidence, however, that a nitrogen atmosphere retards the fading of watercolors.

The Getty Conservation Institute, as well as Gilberg and Grattan, concluded that Ageless is a rapid and efficient oxygen scavenger (Gilberg and Grattan 1994). Its use in an inert, gas-filled, hermetically sealed display case with a moderate leak rate should maintain the oxygen content at a very low level for several years. An environment with an RH of 53% or above is recommended. Both the level of the oxygen content and the interval after which an Ageless-equipped case will require a replacement and flushing can be readily predicted if the case leakage rate is known.

There are many devices for measuring RH; they range from aspiration and sling hygrometers to thermohygrographs, dial hygrometers, cobalt salt strips, and data loggers of various kinds. Thomson and Brown have described the pros and cons for a number of devices, showing how unreliable they can often be, either because of an instrument's poor accuracy or lack of calibration or because of mistakes made by the person manipulating the instrument (Thomson 1981; Brown 1994). Suggestions for the monitoring of showcases include a special built-in sensor with digital readout or a printer (Mayer 1988). A number of small measuring devices have also been used to keep track of activity inside the microclimate boxes.

Diamond placed a small Edney dial hygrometer inside the box, after checking it for accuracy against a sling psychrometer. Diamond's microclimate box covered both picture and frame, so the hygrometer could be placed flat at the bottom of the vitrine, enabling the viewer to monitor the environment from the front of the box (Diamond 1974).

The vitrines used by Rothe and Metro of the J. Paul Getty Museum had been tested with small thermohygrographs from Pasturelli and Rapkin (Rothe and Metro 1985). They were not as accurate as much larger and more sophisticated thermohygrographs but were, in this
instance, proved to be reliable, since they provided warning about air leakage. According to Roult and Martino, the only evident disadvantage is a necessity for frequent monitoring because no printout (that can be read later) is produced.

Paper RH indicators with impregnated bands of cobalt salts change from pink to blue in relation to the ambient RH. This type of indicator has been used by most modern authors, and a thorough investigation into their effectiveness has indeed proved them to be reliable and long lasting (Daniels and Wilthew 1983). A reference color against which to compare the RH values on the strips is recommended. As dial RH measuring instruments have hair, paper, or special plastic sensing elements, they need frequent recalibrating; strips, in contrast, are not altered over time.

Placement of the cobalt strips next to the painting within the vitrine is necessary to obtain an accurate reading. Since this is aesthetically not a very pleasant solution and distracting for spectators, other placements have been explored. The cards have often been placed on the back of the boxes, but microclimate boxes that fit within the frame can only be monitored when the painting is turned, a procedure that requires much time-consuming and unnecessary handling of the object in order to track the changes in the microclimate box.

When daily monitoring of a microclimate box and its painting is not feasible, a continuous record of activity is possible only with small data loggers. Inspired by the National Gallery in Washington, D.C., the Mauritshuis began monitoring the RH and temperature within microclimate boxes using ACR data loggers (Wadum 1992). The small logger was mounted behind the panel on the inside of the backing lid of the microclimate box, with its communication socket in the frame of the vitrine. This method allowed for initialization of the logger inside the box without its being opened. When the painting was traveling, the courier made backups of the logged RH and temperature after arrival at the destination museum. Then, a new interval of logging (typically around three months) was set for the loan period to follow. The courier and the registrar could then evaluate the transit period and eventually arrange for improvements before the return of the painting. These small loggers make it possible to keep a complete record of a specific painting's climatological history, starting from the moment of installation.

Discussing the aesthetics of microclimate boxes can initiate a heated dialogue between most curators and conservators, as well as among the public. Most people would probably prefer being close to an object of study, without having the feeling of looking into a vitrine. Paintings in vitrines seem remote—the vitrine forms a barrier between the spectator and the artwork.

As previously discussed, microclimate boxes have developed from vitrines hanging on the wall, enclosing painting and frame inside, to small boxes placed behind and within the frame. This evolution clearly reflects the goal of distracting the spectator as minimally as possible. De Guichen and Kabaoglu once made an ironic list of recommendations regarding the optimum manufacture of a showcase (de Guichen and Kabaoglu 1985). Almost all of their "guidelines" could also apply to the microclimate boxes: (to wit: one suggestion, to "be sure to display the locking mechanism.
prominently," reflects the assembling screws or painted backing boards that make a disturbing impression on many a microclimate box).

During the installation of a painting in a microclimate box, dust can become a nerve-racking nuisance ("Avoid sealing the showcase too tightly, because exhibits always look better when covered with a uniform coat of dust," de Guichen notes). Many microclimate boxes on display do show small specks of dust on the inside of the glass, and cleaning them out is impossible without dismantling the whole box. A practice usually acceptable only when the box has returned to the controlled environment of the lending museum.

The protective Perspex or glass is another main issue. Many microclimate boxes recall de Guichen's "helpful" suggestion to "polish the glass of your showcase to a mirror finish." Any glazed painting, particularly a darker one, reflects at certain viewing positions. Perspex has the most reflective qualities; coated and low-reflection glass can reduce the amount of reflection to a minimum. In some instances, detection of the protective glass front is impossible without specific inspection (Saunders and Reeve 1993).

The small (366 × 237 mm) François Clouet picture that Diamond placed in his microclimate box is aesthetically and physically delicate (Diamond 1974). It has an extremely finely wrought rosewood frame inlaid with silver and mother-of-pearl, "clearly not the sort of thing you just put in a box and screw to the wall," he states. The proportions of the box, as well as the color and texture of its lining, were thus critically considered in the design; ultimately, the museum agreed that the picture actually benefited from its more aesthetic installation, as well as its new, larger presence on the gallery wall.

This particular approach for a small picture has also been used in the display of fragments of altarpieces on gallery walls. These so-called shadow boxes not only serve as buffers but also enhance the object's physical presence.

Rothe and Metro state that microclimate boxes should not be too visually overpowering, since their main function is to protect the painting (Rothe and Metro 1985). Rothe and Metro's Perspex box for the Simone Martini also covered the painting's original, inseparable frame; the box around the Fayums—which, for obvious reasons, do not have frames—could, of course, only be of a showcase type. Here the objects became, in a sense, archaeological fragments; without the microclimate boxes, the visitor would not have the opportunity to view these fragile objects.

With a microclimate box covering both the painting and the frame, the vitrine does not have to be built to fit the panel painting exactly. Rather, it can be made in standard sizes, allowing reuse for another painting at a later date. Disadvantages include the high reflection factor of Plexiglas and the fact that some viewers find the box aesthetically displeasing.

Ramer, however, suggested that to fulfill aesthetic requirements, the microclimate box around his Netherlandish painting should be fitted into the extended rabbet of the picture frame (Ramer 1984). The box in this case "pretends" not to be present, leaving the viewer's attention focused on the painting. Most of the more recent constructors of microclimate boxes (i.e., Cassar, Edmunds, Bosshard, Wadum, Sozzani) included these considerations, preferring small, narrow boxes made to fit behind the frame.

The use of low-reflection glass of low iron content (which takes the green out of normal glass) has limited the amount of disturbance to a minimum.
Encapsulating panel paintings in microclimate boxes in this manner reinforces the protection and care of our cultural heritage, benefits that promote an increased willingness by museums to lend their most vulnerable panel paintings.

It would be wrong, however, to suggest that all problems can be overcome by fitting a panel painting in a microclimate box. More secure microclimate boxes with better seals against leakage have yet to be made. Also, the problem of adequate thermal buffers when a painting is on loan has not, in many instances, been satisfactorily handled. The level of shock or vibration to which a paint film and its carrier are exposed during transit still begs further definition: a better solution to this trauma must be found. Correct acclimatization in historic buildings and museums also requires much more research and attention, if the dimensional movement of painted wood that is displayed or stored is to be stabilized.

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Notes

1 Standards for sealed transport cases of wood painted with water-resistant paint, or lined on the inside with a nonpermeable water-resistant membrane, are given by Stolow (1965). The standards include precise volumes for wood and silica gel in the cases.

For maximum thermal insulation, a case should have thick walls, high thermal capacity, small thermal conductivity, and small surface area (Stolow 1957). Stolow gives examples from air transit, in which hulls of planes may reach temperatures of \(-40 ^\circ\text{C}\), or in which hulls have no pressure correction, and therefore, at low pressure, air escapes the box. Upon a plane’s return to earth, air again enters because of the higher pressure, and this air may be of an undesired climatological condition. Therefore, cabin-pressure control and temperature control during air transit are important factors to take into account.

2 Buck concludes that while good moisture barriers may almost completely insulate a panel from short-cycle humidity variations, they may nonetheless be surprisingly ineffective against seasonal cycles. For recent studies on moisture buffers applied on panel paintings, see Brewer 1991.

3 Buck suggests that the larger fluctuations in RH in the United States could be the reason for a tendency to cradle panels more often in the United States than elsewhere (Buck 1962). He further demonstrates that a cradled test panel that was kept in a heated, dry room for several months showed shrinkage of roughly 1.4% in its width, with the members of the cradle sticking out at the sides. Buck invites rheologists to communicate with restorers to learn about the laws that govern the flow and deformation of materials.

4 The addition of hygroscopic material (having the same quick response as gelatin) at the rear of the canvas and the sealing of the reverse by a loose lining would help reduce the rate of response of the glue. Glazing with acrylic and a backboard creates further enclosure for the original object and thus provides protection from unwanted reactions to temperature changes (see Lackney 1990).

5 Investigation of thermal properties of transport cases is important when traveling exhibitions are on the move. During travel, the cases may be exposed to unforeseen temperature conditions, and the use of thermal linings can offer significant protection and permit greater RH stability within the cases (Stidow 1966). It is also possible to maintain constant moisture content of soft-packed paintings by controlling temperature, provided that the moisture barrier used as a wrapping material (polyethylene) is well sealed (Saunders, Sirwell, and Stasford 1991).

An early example of polyethylene as a tight wrap for paintings coming from Europe to Canada is recorded by Thorsen (1961).
6 When wood and other moisture-containing materials are heated, they give off moisture. At the same time, heated air can hold more moisture, so together the wood and air reach a new equilibrium. In an empty case of nonabsorbent material such as glass or metal, a rise in temperature will cause a fall of RH, and vice versa. In a case holding a quantity of wood, the situation is reversed: a rise in temperature will cause a rise in RH. When wood gets hotter, it will give up moisture unless the surrounding RH rises. In a closed case, the RH will indeed rise because of the moisture given off by the wood, and the two tendencies will counteract each other. At median humidity, wood contains about twelve times as much moisture as air, volume for volume. Therefore, wood or other cellulosic materials will have the dominant effect on the interior of a small microclimate box.

Thomson showed in practical experiments that a ratio of 120 g wood per 100 l air achieves a constant RH at changing temperatures (Thomson 1984). The change of RH will not exceed about one-third of the temperature change (°C) and will be in the same direction—provided that there is no entry of outside air of a different RH into the case. For ratios greater than 1 kg of wood to 100 l of air, the standard curves for wood equilibrium may be used.

7 Based on the rather dramatic climatological changes occurring in Canada, Stolow demonstrates his findings on different forms of small environments within packing cases (Stolow 1967). It is seen that a sealed case is capable of maintaining a certain level of RH when it contains wood or similar cellulosic materials preconditioned to the desired level. The use of silica gel permits exposure to even greater external temperature changes while it retains the same RH control.

8 The diffusion coefficient of water vapor through air is about $0.24 \text{ cm}^2 \text{ sec}^{-1}$ (Padfield 1966). This is about twice the coefficient of the other gases found in air. The coefficients for diffusion through wood is about $1.2 \times 10^{-4} \text{ cm}^2 \text{ sec}^{-1}$ for water vapor, and $8.75 \times 10^{-4} \text{ cm}^2 \text{ sec}^{-1}$ for carbon dioxide (see Stamm 1964). This means that 1 m$^2$ of wood allows as much air to diffuse as 3 cm$^2$ of hole through it, and it leaks water vapor as fast as a 9 cm$^2$ hole.

9 Weisbraub introduces a number of tools for determining which sorbents will be most efficient within a specific RH range (Weisbraub 1981). In the 1978 International Council of Museums Conference on Climatology in Museums, there was a general consensus that a sorbent should be temperature independent and have as large a surface area as possible (e.g., powdered silica gel).

10 As a consequence of the many different types of micoclimatic variations being introduced by various authors, Cassar proposed standardization of symbols to be used in classifying the more commonly used types of case construction designs (Cassar 1984).

11 Many woods (especially British and European oak) give off organic acid vapors, which can accumulate and ruin many types of objects, including those of metal, marble, marmarine such as mother-of-pearl and shell, and paper and textiles, in cases where the exchange of air between inside and outside has been reduced to a minimum. All adhesives, adhesive tapes, and sealants used should be tested for stability to ensure that none give off harmful vapors.

12 The choice of a right sorbent is essential and should be considered together with the RH level required for the specific object. Therefore, it is essential to consider the isotherms for the different kinds of sorbents before a decision is made.

13 The RH control module designed to service a number of display cases is based on a mechanical system combined with a buffering agent such as silica gel (Lafroncine and Michalski 1984). A plastic tubing system distributes the well-conditioned air to a number of display cases, relying on an air exchange in the display cases of a certain amount per day. Air in the display cases equipped with this humidity-control module should be supplied at a rate of at least double the natural leakage. One RH-control module can thus control many display cases. The conditioned air enters the cases through the tubes and leaves again via natural openings that permit leakage. There is no active temperature control—the module passively follows the room temperature. The system, therefore, works only if none of the cases is cooler than the control module.

14 The salts used were hepta- and hexahydrates of zinc sulfate, which are at equilibrium in an atmosphere of 33% RH at a temperature of 15 °C (Currier 1936).

15 Stolow gives as an example a case for which the wood and silica gel are both 1000 g and the RH is kept stable (Stolow 1967). Even a smaller ratio of gel to wood would have a stabilizing effect, buffering the internal RH against temperature changes. If silica gel is used, it should be packed in a way that gives it as large a surface area as possible.
16 The change of RH is somewhat more than a third of the imposed temperature change, and in the same direction as the change (e.g., if the initial RH was 50%, the temperature 20 °C, and the case exposed to 30 °C, the resulting RH would be 73.5% RH; if the case were exposed to a temperature of 10 °C, the final RH would then go to 66.5%).

17 Stolow recommends a silica gel granula, not exceeding 3 mm, spread out thinly over as large a surface as possible. He also advises the use of a dry weight of silica gel at least double the weight of the material to be protected (Stolow 1966). In the box discussed, 453 g of silica gel was used.

18 The M value is the “specific moisture reservoir” (moisture gain in g/kg for a 1% rise in RH).

19 Theoretical and experimental research at the Canadian Conservation Institute has shown that if gaps at the top and bottom seams of a case are smaller than 0.1 mm, the leakage rate of the case will be less than two air changes per day (Michalski 1985).

20 Previously the panel underwent conservation treatment as follows: The reverse was covered with Saran F-300 (a copolymer of vinylidene and acrylonitrile, soluble in methyl ethyl ketone) and a layer of glass fabric, in an effort to stabilize the panel. Prior to this treatment, it was noted that there was a dark, water-soluble layer (skin-gel sizing perhaps) between the paint film and the wooden support. Four other Fayum portraits (two painted in encaustic, two in a water-soluble medium) were examined, and it was concluded that the intermediate layer between paint and wood was indeed very hygroscopic. The Saran and glass fabric on the reverse side of the Fayum on loan may have altered the warpage pattern, as the panel developed a pronounced concave configuration.

21 The museum display cases used in the Sainsbury Centre and their exchange of water vapors are being evaluated. The hygroscopic half-time is calculated, as is the half-life for water diffusion in the cases. The better sealed the case, the longer the half-life (Sainsbury Centre, 1984).

22 A large amount of nitrogen was passed into the case, via the access hole where the Perspex top was secured. Increasing the concentration of nitrogen acted to deplete the oxygen level to approximately half its normal value. Immediately after the introduction of the nitrogen, a small volume of carbon dioxide was added, which increased the carbon dioxide level of the air in the case to about ten times its normal value. The following day, small samples of gas were extracted and injected into a gas-liquid chromatograph in order that the oxygen and carbon dioxide content might be determined. In this way the gradual loss of carbon dioxide and the invasion of oxygen could be monitored. The half-lives for the exchange of oxygen and carbon dioxide gases with the display case were calculated to be 2.3 and 2.7 days, respectively.

23 The case was designed in collaboration with Helmut Guenschel, Inc., Baltimore, which actually built the case.

24 Ranacher’s concept was based on the microclimate boxes from the Philadelphia Museum of Art (Ranacher 1988).

25 This box was made by the California company of G. F. Wight Conservation, following the principle laid out by Bosshard and Richard.

26 This result is explained by the specific characteristics of Art-Sorb, which according to Bosshard desorbs or absorbs different amounts of humidity depending on temperature. However, contradictory reports by several authors as to the nature of the silica gel or Art-Sorb emphasize its stability despite changes in temperature (Richard 1991).

Richard tested two vitrines of different size: one with an RH of 50%, the other with an RH of 30%. After three months the RH in the small vitrine had decreased to 1%, the large vitrine to only 0.5%. This result proves that the half-time will be around two years for the less sealed of the two. Both tests were made in empty vitrines. It is concluded that the climate would have been even better with the panel inside, as the hygroscopic material would help stabilize the microenvironment. During transit the same benefit was received: 16 °C fluctuations in the vehicle, but only 2 °C fluctuations in the box. RH fluctuations of ±7% were recorded in the box, but only 1% were recorded in the case, as it was kept in a well-insulated transport crate.

27 The box was made as a joint project with the Museum Boymans – van Beuningen, Rotterdam, which had the skilled technical staff required for its production. Nicola Contaras, Lask Shrub
van der Loeff, and Carol Pottasch all contributed to creating this first box, which was designed by André van Lier (Wadum 1992).

28 The safety glass used for the first model was Novillex; at present the thinner and less-costly Mirogard Protect Magic, Low-Iron, is used.

29 A method later found not advisable (Wadum 1993).

30 ACR data loggers from ACR Systems, Inc., were used. They were typically set at measuring intervals of 30 seconds during transit and at 10 minutes throughout the duration of the loan.

31 See note 25 above.

32 The Pelletier effect describes the absorption or emission of heat when an electric current passes across the junction of two dissimilar conductors.

33 The microclimate boxes were initially made by Smitt Mobile Equipment B.V., Oud-Beijerland, the Netherlands; they are now produced by the technical staff of the museum, according to the most recent manual.

34 The author is indebted to Susanah Edmunds at the Victoria and Albert Museum for information on this early microclimate box.

35 Pastorelli and Rapkin Ltd., London, was taken over in 1983 by M and T Precision Instruments Ltd., Enfield.

36 The Humidical Corp. type card no. 6203-88 seemed to satisfy most users.

37 The author is indebted to Sarah Fisher, National Gallery of Art, Washington, D.C., for sharing her information on measuring devices.

38 Shock monitoring may also constitute part of the recording of a painting in transit. The most recent literature on this topic can be found in Mecklenburg 1991, in which several authors deal with the subject. The author has had fruitful discussions on this topic with David Saunders of the National Gallery, London.

39 The logging interval during transit would often be 30 seconds; the interval during exhibition would generally be 10 minutes.

40 With regard to the investigation into the performance of humidity sensors, M. Cassar is conducting a comparison of ten different sensors for stability, drift, and long-term performance. This work in progress will provide valuable information for the assessment of measurements obtained by study of artifacts on display or in transit.

Materials and Suppliers


Ageless, Ageless Z, Ageless Z-200, Ageless-Eye, Mitsubishi Gas Chemical Co. Mitsubishi Building, 5-2 Marunouchi 2-chome, Chiyoda-ku, Tokyo, 110 Japan. (Different types of Ageless are available depending upon the water activity (WA) of the packaged commodity: Ageless Z WA < 0.85%. Ageless A-200 indicates that 200 ml of oxygen can be absorbed. Ageless-Eye is used as a color-changing oxygen indicator.)


Edney dial hygrometer, Edney 2 in dial hygrometer (ref. PH2P), M and T Precision Instruments Ltd., Queenways, Enfield, Middlesex EN3 4SG, U.K.

Grant Squirrel Data Loggers, Grant Instruments Ltd., Barringtion, Cambridge CB2 5QZ, U.K.

Humidical Corp. type card no. 6203-88, Humidical Corp., 465 Mt. Vernon Avenue, P.O. Box 464, Colton, CA 92324.

Kaken Gel, Kaken Pharmaceutical Co. Ltd., 2-28-8 Honkomagome, Bunkyo-ku, Tokyo, Japan.

Lexan, General Electric Plastics, Old Hall Road, Cheshire M33 2HG, U.K.
Microclimate Boxes for Panel Paintings

Microgard Protect Magic, Low-Iron, Deutsche Spezialglas AG (DESMO/SGH), Postfach 2032, 31074 Grünental, Germany.

Nikka pellets, Nippon Kaseikako Co Ltd. (Nippon Activated Clay Co Ltd.), 7th Floor, Daisan-Azuma Bldg., 1, Kandahirakawacho, Chiyoda-ku, Tokyo, 110 Japan.

Saran F-300, Dow Plastics, 2020 Willard Dow Center, Midland, MI 48674.

Squirrel, Eltek Ltd., 35 Barton Road, Hastingfield, Cambridge CB3 7LL, UK.

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