A COOLED DISPLAY CASE FOR GEORGE WASHINGTON'S COMMISSION

Tim Padfield, Martin Burke and David Erhardt

Abstract

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A COOLED DISPLAY CASE
FOR GEORGE WASHINGTON'S COMMISSION

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SUMMARY

A cool display case was made for a vellum document. A close fitting airtight container was used. This maintained a nearly constant relative humidity on cooling, but care was needed to minimise temperature gradients. Thermoelectric coolers were used. The case performed satisfactorily for one year with no change in internal moisture content.

Introduction

The Museum of American History in Washington, DC recently put on an exhibition about the life of George Washington, which included the commission, written in 1775, appointing him Commander in Chief of the Continental Army. The Library of Congress, which lent the document, asked that it be kept at about 16°C, some six degrees cooler than the museum gallery, and at 40-50% relative humidity. We designed and built a case to display this piece of vellum during its year on exhibition.

We used the simplest possible method: sealing the document in a small airtight container and cooling it by means of the Peltier effect, which is the absorption or emission of heat when an electric current passes across the junction of two dissimilar conductors.

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 relative humidity. It impedes unnecessary handling, excludes air pollutants and gives good protection against flood, fire and vandalism.

The only unusual dangers come from the cooling system, which brings electricity into the case, and from the possibility of air leakage into the container which would cause a dangerous rise in relative humidity around the document.

The climate inside a cooled box containing paper

The document is vellum but the backboard and mat, which together make up most of the weight of the assembly and therefore most of its moisture content, are of paper. Vellum and paper react similarly to changes of RH and of temperature so the following discussion is based on the behaviour of paper made from cotton cellulose, for which more data are available.

Paper always contains some water loosely bound within the fibres. The amount usually depends on the temperature and on the water vapour content of the surrounding air. At room temperature paper contains thousands of times more water than an equal volume of air, so in a sealed box full of paper it is the paper which controls the relative humidity of the surrounding air, if both are at the same temperature.

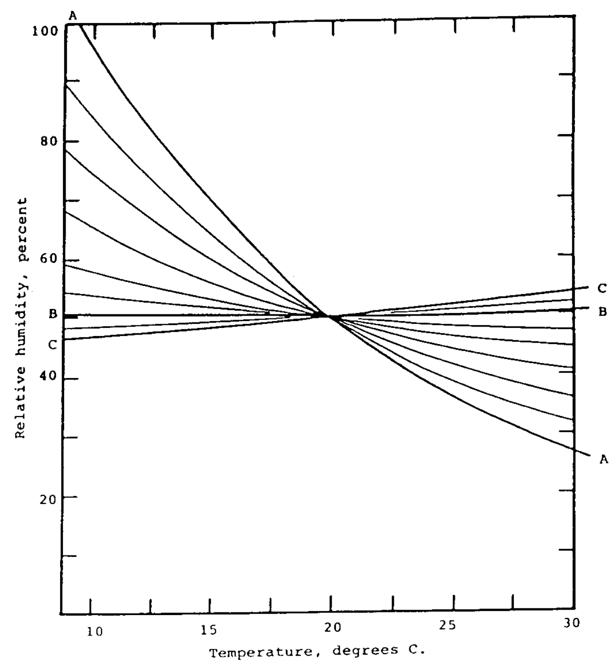

Figure 1. Temperature and relative humidity within a sealed box containing cotton and air in various proportions, originally conditioned to 50% RH at 20°C.

If the box contains only air. The RH rises with falling temperature (curve A), reaching 100% at 9.5°C.
If the box is stuffed with cotton the RH in the small residue of air falls slightly with falling temperature (curve C).
Perfect compensation is provided by 0.6 litres of air for every gramme of cotton (curve B).

Imagine a box containing air and paper equilibrated to 50% relative humidity at 20°C. The box is sealed and the temperature allowed to change slowly. Figure 1 shows what happens to the RH inside.[1] If the box is stuffed with paper, leaving hardly any room for air, the RH moves along curve C. The paper is imposing on the space around it that RH which is now in equilibrium with the amount of water the paper contained at the moment it was sealed up, the residual air having scarcely any water content of its own. Curve A shows how the RH would change if there were no paper in the box. If there is some paper and plenty of air the influence of each on the other leads to an intermediate course: the almost horizontal, almost straight curve B corresponds to one gramme of paper to each 0.6 litres of air. A container with more than about one gramme of paper per litre of air enjoys a reasonably stable RH as the temperature varies, and this rule of thumb holds good over the whole range of ambient temperature.

This happy condition applies only to a slow temperature change imposed uniformly on paper and box. This is what we aimed to do with George Washington's Commission but because the container was cooled from below and most of the heat gain was through the upper surface some small permanent temperature gradient across the container was inevitable. We also had to design for accidental sharp changes in ambient temperature. How would the sealed box react?

Suppose that the document in its paper mat remains at 20°C while one wall is at some different temperature. The concentration of water vapour will remain unchanged and uniform everywhere in the box, so the RH at any point will be determined by the temperature at that point, according to curve A in figure 1. Paper will neither gain nor lose water to compensate for this change if it remains at a constant temperature. It "disappears" from the climate controlling process. It is important to realise that absorbent materials such as paper or silica gel only function as RH buffers if they are at the same temperature as the air, or object, which is to be buffered.

If the temperature should fall to below 9.5°C at any wall of the container while the paper remains at 20°C, the RH at that wall will reach 100% and water will condense. This reduces the water vapour concentration in the air and now the paper will release more water vapour, which will again turn to dew on the cold wall. This distillation process will tend to dry the paper. Water from the cold wall may flow to the paper and soak parts of it. The result will be brown water marks.

From this analysis of the closed box with paper we developed a specification for the display case.

To prevent mould growth the RH must always stay below 65% everywhere in the case. This means that no part may be more than about four degrees cooler than the paper during steady operation. We allowed ourselves a maximum two degrees difference between the document temperature and the lowest temperature at the walls of the sealed case when it was in steady operation. The estimated temperature gradient across the assembly of document and mat was one degree. This would cause a 3% RH range in the interstitial air and a negligibly small variation in moisture content.

The display case must be double glazed. In the event of catastrophic cooling of the gallery the other exhibits will need first aid first because the danger to our exhibit is lessened by good insulation and by its coolness.

Unexpected sudden warming of the case should cause no climatic problems at all because the walls are insulated and the lid contains no water, so the reverse movement of water from the walls and nearby air into the paper can only occur to a trivial extent.

An important aspect of climate control in a cooled container without mechanical RH control is that it must be perfectly air tight. Any leakage of warm air into the container will cause an increase in moisture content of the paper. The incoming air increases in RH as it cools down and the paper absorbs water from it. For example air at 20°C and 50% RH reaches 65% RH if cooled to 16°C. We allowed for some leakage and put extra paper in the enclosure to increase the RH buffering capacity. The most important precaution however was to put a humidity sensor in the enclosure. This was not just to measure relative humidity during correct operation, which we confidently assumed would conform to theory, but to detect leakage of air.

Another important design condition was that materials used within the case should not release harmful gases. The common practice of using new plywood and fresh paint in showcases for temporary exhibitions causes release of vapours of formaldehyde, acetic acid and other organic pollutants. Airtight enclosures are a positive conservation measure in such an environment.

As a further guard against pollution the card strips put in the case as a buffer against the effects of air leakage contain calcium carbonate to absorb acid gases.

The other features of the design were that it must allow easy removal of the object in an emergency without trailing cooling equipment and wires along with the precious container. It should resist fire for as long as possible because fire is the main hazard to any case containing electrically operated technology. The sealed case will prevent smoke damage to the paper and it will of course be waterproof.

The Final Design

The most demanding of these various requirements was the small temperature gradient allowed. This was difficult to meet because the commission was shipped from the Library of Congress matted and sandwiched between 6 mm acrylic sheets, which are not good heat conductors.

The entire system is illustrated in a cut away diagram, figure 2. The document assembly was laid in an aluminium tray with a 12 mm thick base and even thicker sides. This conducted heat from the two tiny (20 mm square) cooling devices so well that the inside walls and floor were of uniform temperature within one degree. The tray was laid horizontally to prevent convection currents. Sides and base were lined with cork insulation 25 mm thick. The glass lid was supplemented by the acrylic glazing of the showcase which prevented warming draughts. When the tray was seven degrees below ambient temperature the document was more than six degrees below.

Our other main concern was to prevent air leakage. We used orthodox vacuum technology. A viton O ring lightly greased with hydrocarbon lubricant lay in a square section groove in the aluminium wall. A lid made of armoured glass lay on the aluminium, slightly compressing the O ring. The glass was held down by fourteen spring steel clips. These were made easy to remove because the tray and glass were heavy and in an emergency one could move faster clutching only the inner sandwich of acrylic sheet.

The tray rested in the cork insulation which in turn sat on four wooden posts attached to the showcase. The entire tray could therefore be lifted out once the showcase lid was removed. The only part of the cooling system that came with it was a slimy residue of the silicone grease used to give good thermal contact between the thermoelectric coolers and the tray.

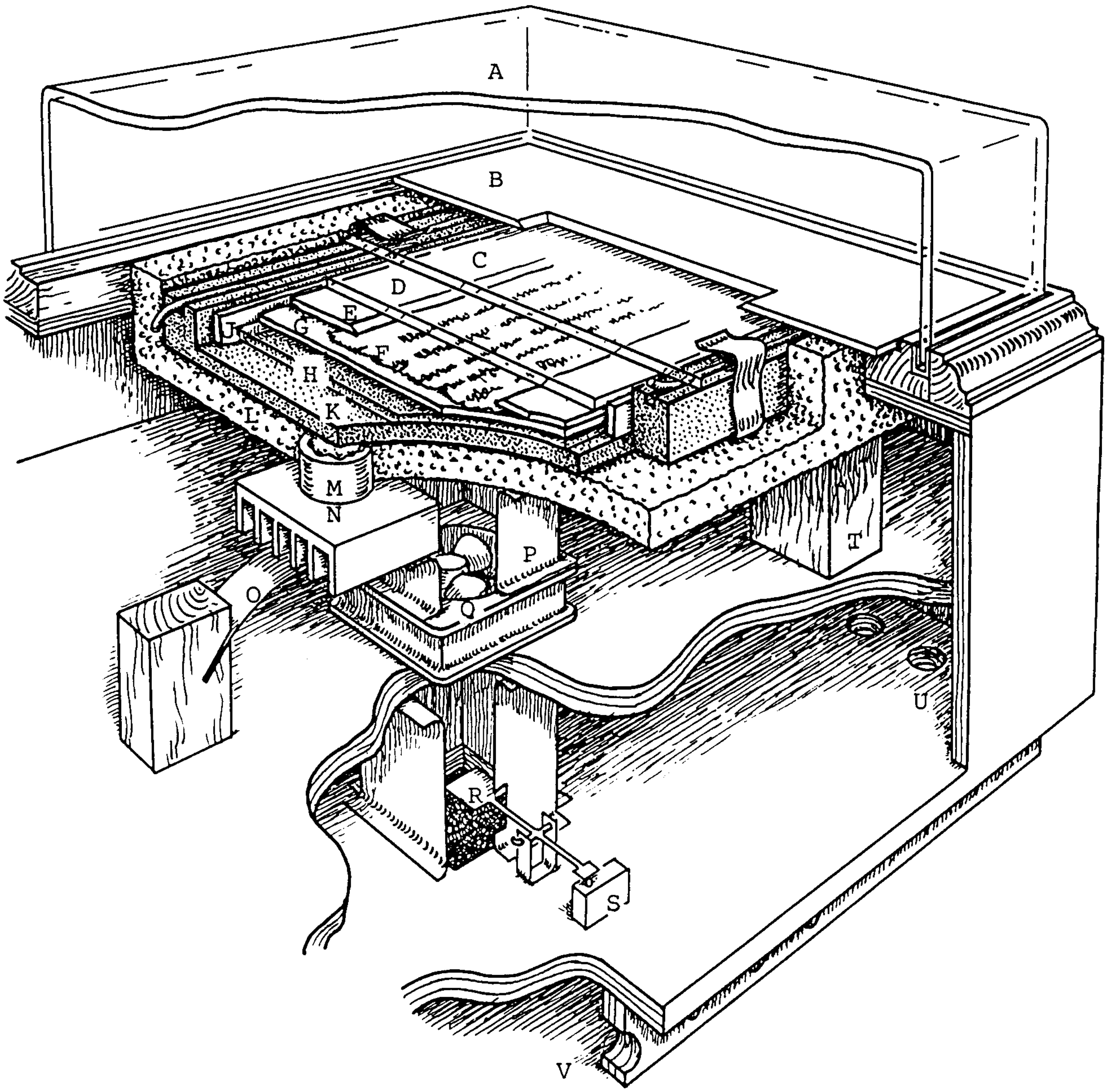

Figure 2.

Cut away diagram of the display case. The document F is enclosed by mat E and back board G. All this is sandwiched between Plexiglas sheets D & H and bound together with adhesive tape round the edges. This sealed assembly lies in the aluminium tray K and is covered by armoured glass C. A viton O ring lies in a groove round the edge of the tray. The glass is pressed down onto the O ring by spring steel clips. The tray is insulated by cork L. All of this is supported within the showcase by four wooden blocks T so that it can be lifted out easily once the Plexiglas case top A has been removed. A frame B conceals the cork insulation and steel clips.

The thermoelectric coolers M and the heat dissipating fins N are pressed up against the aluminium tray by a spring O. The duct P directs cooling air from the fan Q over the fins and eventually out through the holes U in the base of the case. Air comes into the case through holes V and is drawn up past the hinged plate R, which operates switch S when it is pressed up by the flow of air.

The Cooling System

The danger of creating rapid temperature changes and steep gradients caused us to design a cooling system barely adequate for the job when running flat out. This simplified the control system greatly. The cool case hung seven degrees below the controlled temperature of the gallery. The cooling system can fairly easily be altered to work in a variable environment but it would need more power and it would be less efficient.

We used two thermoelectric coolers.[2] These are made up from short lengths of two different semiconductors alternating in series. When a current is passed every second junction gets cold and those in between get hot (Peltier effect). The junctions are arranged in a compact slab, 20 mm square by 4 mm thick, so that one side gets hot and the other side cold.

Each of the two coolers was clamped between an aluminium cylinder on the cold side which penetrated through the thermal insulation to the tray and conducted heat away from it, and a set of aluminium cooling fins on the hot side. The fins were cooled by a stream of air as shown in figures 2 and 3. The circuit diagram and the various safety devices are shown in figure 3.

The heat loss from the insulated tray was about five watts. The total power going into the case to supply the coolers and fan was nearly forty watts. Thermoelectric coolers are not very efficient and a further loss of efficiency was caused by water condensing on the cold surfaces close to the coolers which were below the dew point temperature of the air. We did not discourage this process because it functioned as a thermostat preventing cooling of the tray below the dew point, which would be undesirable because dew would condense on the outside of the glass cover and obscure the document within. We eventually used a wax resin mixture around the coolers to prevent condensed water from corroding them. The water migrated to the cooling fins and evaporated into the air stream.

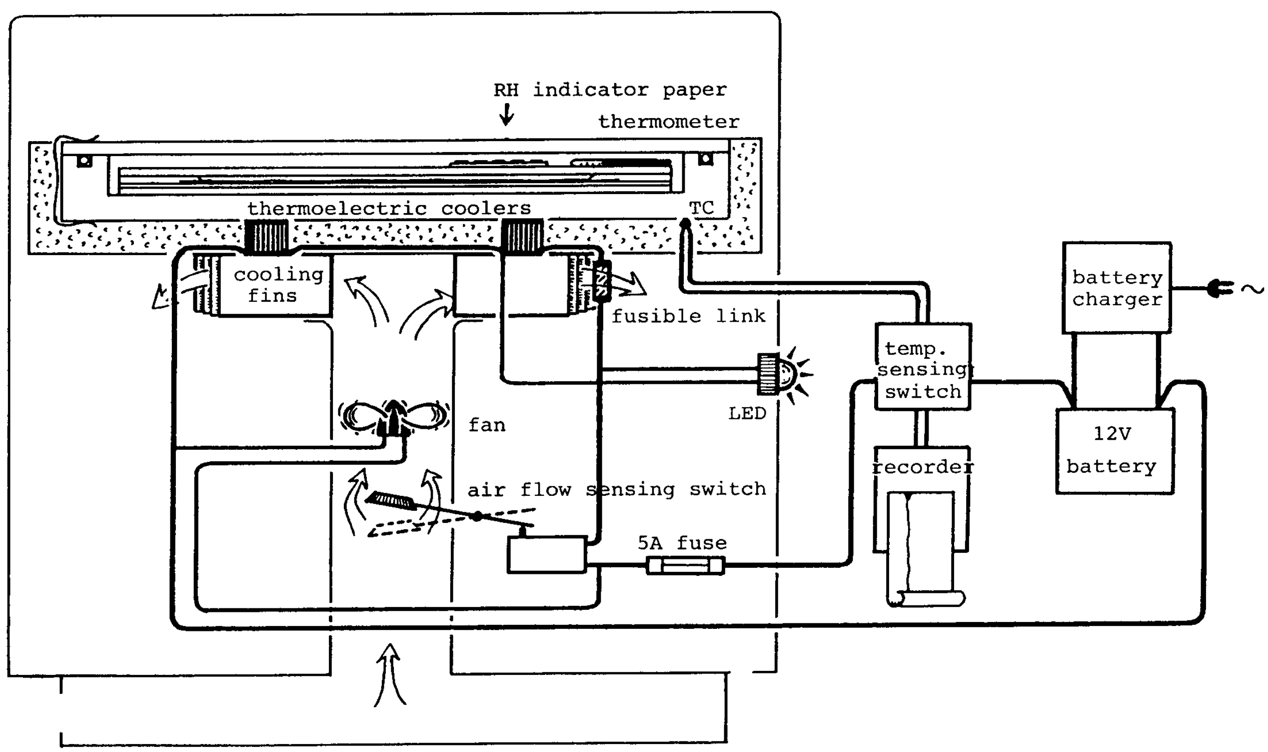

Figure 3 Circuit diagram. The thick line is the main cooling circuit. The battery charger and battery provide both a reserve of power and a constant voltage source. The temperature sensitive switch breaks the circuit if the tray warms above 25°C. The 5A fuse protects against overheating due to a short circuit in the display case. The air flow sensing switch closes the main circuit only after the cooling air flow is established. If this switch sticks shut a fusible link breaks the circuit if the cooling fins get hot. Correct operation is shown by a small light emitting diode. If either cooler fails to conduct the light goes out. If one cooler short circuits the light goes out, if the other cooler short circuits the light burns out. The temperature of the tray is continuously recorded. The temperature above the document is shown by an alcohol in glass thermometer. Leakage of air into the case is revealed by the rise in RH indicated by the colour change of cobalt salt impregnated paper.

This cooled case operated for about a year. It failed twice. Once the fan failed to re-start after a power failure and had to be prodded into action. Then one thermoelectric cooler failed through corrosion by condensed water. Both coolers were replaced and protected by wax-resin mixture. The result of each failure was a slow warming of the exhibit to room temperature and no damage was done. At the end of one year the case was removed from exhibition. When the glass lid was raised the cardboard strips, which had been put in to protect the document against moisture absorption through leakage of air, were quickly removed, put in a polyethylene bag and weighed. They were then allowed to condition to equilibrium with air at 50% RH, 20°C and re-weighed. There was a small weight gain from which we deduced that the document had been maintained in an atmosphere of about 40%-45% RH at 16°C. It went in at 50% RH at 20°C. There was evidently very little leakage because air exchange with the gallery would have pushed the equilibrium RH within the case towards 70% at 16°C.

References and Notes

1. Data for figure 1 were obtained from the psychrometric chart published by the Institute of Heating and Ventilating Engineers and from: A. R. Urquhart & A. M. Williams, The effect of temperature on the absorption of water by soda-boiled cotton. J. Textile Institute 15 (1924) T559-573.

2. A. F. Joffe, Semiconductor thermoelements and thermoelectric cooling. London 1957.

Technical details: The document measures 500 x 240 mm. The inside of the aluminium case measured approximately 750 x 450 x 50 mm. The total weight of paper within the enclosure was 400 g, the air volume was about 0.004 m^3. The insulation was 25 mm of cork round sides and base.

The thermoelectric coolers operated at 6V, 2A each. They were made by Melcor/Materials Electronic Products, 922 Spruce Street, Trenton, New Jersey 08648 USA. The cooling fins had an area of about 60,000 mm^2. The cooling rate of the box was 5 degrees per hour diminishing asymptotically to zero at 7 degrees below ambient.

The overheating detector was a copper-constantan thermocouple connected to an Omega controller, model 50 T (Omega Engineering Inc. Stamford, CT, USA). This controller was used as a protective switch but it can be used as a thermostat.

The axial fan moved 2 m^3 of air per minute.