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Showcases: a really effective mean for protecting artworks?

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Abstract

Field and laboratory tests have been performed to analyse the response of showcases to environmental factors. The following properties have been tested. Thermal damping. Greenhouse effect and IR absorption of the materials most commonly used for panes. Impact of different types of light sources. Humidity buffering capacity and rate. Inside/outside exchanges and leakage. Penetration and deposition of airborne particles. Advantages and disadvantages of airtight and non-airtight showcases in view of protection against dust, corrosive self-outgassing of VOC and microbiological infection and growth. A proposal is made to indicate all of the case characteristics, and their response to the ambient, with appropriate indexes, which represent the level of quality in view of the specific problems of the user. A quantitative evaluation of each index quality level is also discussed. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Showcases; Microclimate; Exhibit deterioration; Greenhouse effect; Museum lighting and heating

1. Introduction

Showcases are widely used because they are useful to display and protect: in fact they offer a protection against vandalism, robberies and any direct damage that could come from visitors. In addition, often, they are installed for conservation, with the hope that they work as a good ‘filter’ against environmental attacks due to microclimate variations, chemical pollution and action of micro-organism. Showcases are of key relevance in the conservation, and the general principles are reported in two milestone books by Thomson and Stolow [1,2] and, more recently, in [3,4]. The showcase in a museum room is a ‘box in a box’ model, for which another layer of protection works against the ‘aggressive environment’ of modern cities. This model is correct only in the absence of internal perturbing factors, e.g. heating, ventilating and air conditioning systems (HVAC), lighting systems and visitors with their emissions of heat, vapour, organic gases, and transport of external particles. The showcase itself may behave as a greenhouse, emit volatile organic compounds (VOC), or favour the microbiological colonisation, or the life of insects. As a consequence the quality of the micro-environment inside the case cannot be easily controlled although many efforts are done in this direction.

Field and laboratory tests have shown that it is not easy to keep a suitable microclimate inside showcases, for a number of forcing factors, and especially daily temperature and humidity cycles that are in the long run extremely dangerous to exhibits [5]. This paper reports the results of laboratory tests and microclimate observations performed in a number of showcases placed in some museums, i.e. one at the Uffizi Gallery, Florence; one at the Sainsbury Centre for Visual Arts,

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Norwich; two at the Kunsthistorisches Museum, Vienna, and four in the Museo Civico, Padova. The aim of this paper is limited to the microclimate and the air exchanges for the transport of pollutants.

The use of showcases to display artworks may have a positive or negative impact on the life and the state of conservation of exhibits. The aim of this study is to identify the key problems, and to suggest solutions for a better conservation. The characteristics of each showcase should be known and clearly indicated. This could be made with a normative according which showcases should be labelled with internationally agreed indexes which indicate the level of quality with reference to each specific problem, e.g. response to greenhouse effect, temperature change smoothing, humidity buffering, self-generated VOC, penetration of external pollution and so on. This is especially useful to buy the most suitable showcase in view of the specific problems of the user.

2. Experimental apparatus

2.1. Microclimate

The main thermo-hygrometric parameters, i.e. air temperature (*T*), relative humidity (RH) specific humidity (SH), and dew point (DP) were automatically measured with platinum thermoresistance (Pt100, accuracy 0.1°C), electronic psychrometers (accuracy 0.1°C), and thin film capacitive sensors (accuracy 2% RH). Temperature and relative humidity sensors were placed inside and outside the cases, shielded against direct light. Light intensity was measured with a silicon photocell (accuracy 5%).

2.2. Particle size measurement

The size of the suspended particles in air was measured with an optical instrument (Passive Cavity Aerosol Spectrometer Probe), in which in a passive cavity a laser beam is intercepted by the airborne particles. The Mie theory of optical scattering allows the computer to calculate the size; all the particles are counted and classified into 32 size classes, ranging from 0.1 to 10 μm. The spectral distribution density of the concentration of suspended particulate matter was monitored inside and outside a showcase placed in Paleovenetian Room of Museo Civico, Padova with the same instrument. The concentration of suspended particle is expressed in terms of the number concentration density $dN(D)/d(\log D)$, where N is the integral size distribution and D is the particle diameter [6].

3. Results

3.1. Damping of the temperature wave inside showcases

Showcases with thick panes behave as a low-pass filter damping out the dangerous high frequency temperature changes, i.e. protecting artworks against rapid temperature fluctuations or abrupt changes, e.g. in some cases during the cleaning time when windows are open. In a room where the temperature varies harmonically, the theory of heat transfer by conduction through a thin plate (i.e. the glass pane of the showcase) predicts that the temperature inside the case is described by another sinusoid having the same period, but with a damped amplitude and a phase shift dependent upon the pane conductivity and thickness [7]. This simple model, generally used to describe the behaviour of systems with periodic oscillations, cannot be easily transferred to showcases located in museums with heating, or air conditioning. Measurements of the air temperature inside (T_{in}) and outside (T_{out}) showcases have shown that, although T_{in} follows T_{out} with a certain delay, the span of the daily oscillation of T_{in} equals the span of the ambient temperature, so that the daily minimum and maximum values are more or less the same inside the case and in the room. For example, in the Uffizi Gallery a display table $120\times60\times4$ cm^3 with a glass pane, was studied. In this case, both the room and the showcase had temperature cycles with the same amplitude (4°C), but the showcase temperature was smoothed out and delayed by 2 h (Fig. 1). A phase shift without amplitude reduction for the temperature wave inside the case (as expected from the theory) can be explained because the room temperature was not a sinusoid but a square wave. The ambient temperature is governed by a central hot-air heating system that is switched on and off accordingly to opening hours, passing abruptly from the night-time to the day-time

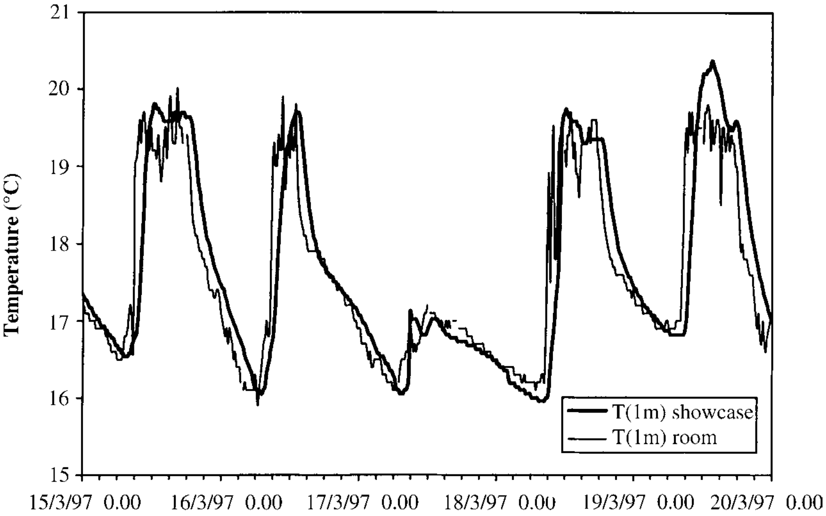

Fig. 1. Temperature daily cycles inside and outside a glass display table at the Uffizi Gallery, Florence. The maximum and minimum values inside and outside are approximately the same. The short period fluctuations in the room temperature are not transferred into the case.

temperature level. In these conditions, the inside temperature reached with some delay the room temperature, and some smoothing was found.

In Museo Civico, Padova, measurements taken inside and outside a glass case ($1\times2\times2$ m^3) showed that the sudden cooling of the room produced by the windows opening during cleaning activities was smoothed out and did not affect too much artworks inside the showcase (Fig. 2).

In certain circumstances, the inside and outside temperatures might look the same, as for the showcases made of a perspex box $40\times40\times60$ cm^3 placed over a metal and wood basement found at the Sainsbury Centre for Visual Arts, Norwich (Fig. 3). This is

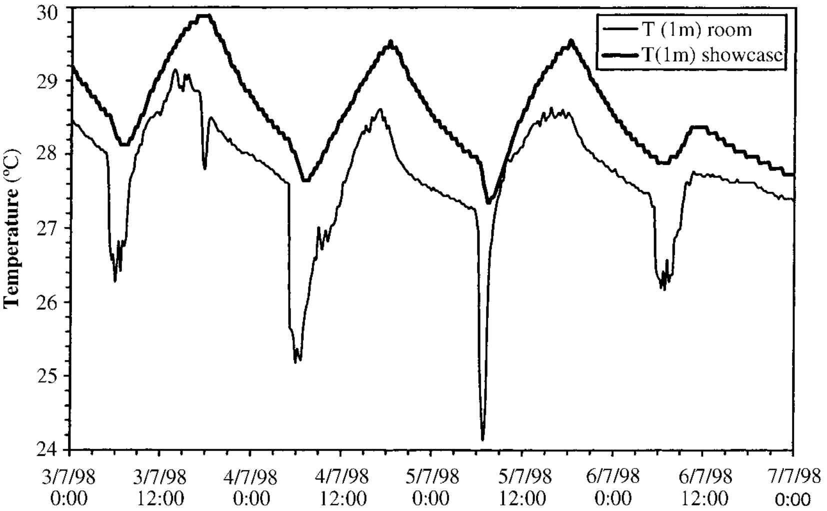

Fig. 2. Temperature daily cycles inside and outside a glass showcase at the Museo Civico, Padova, Collection Room. The sudden cooling that occurs in the room for the opening of the windows in the morning does not affect too much the interior of the showcase.

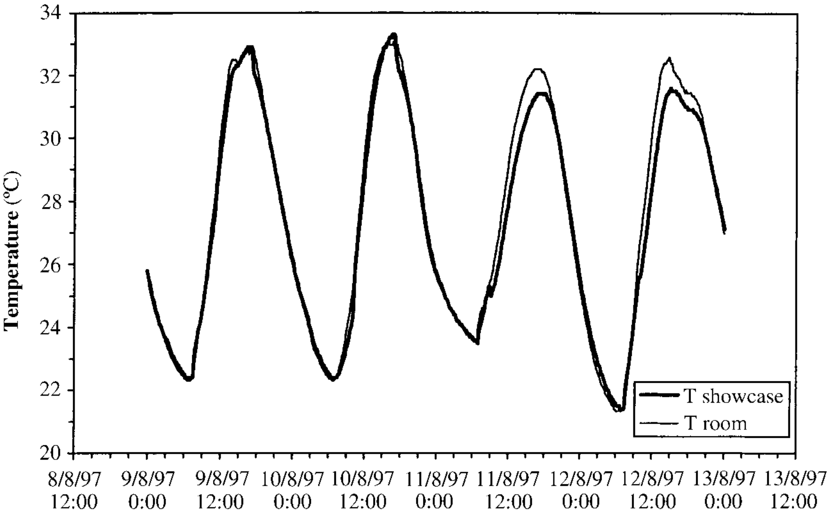

Fig. 3. Temperature daily cycles inside and outside a perspex showcase at the Sainsbury Centre for Visual Arts, Norwich. The external curve is transferred inside almost unaffected by the perspex box.

because in this case the metal frame transmitted heat inside or outside quite rapidly, and the room temperature changed slowly following a 24 h cycle without fluctuations or disturbances.

The damping of the thermal wave inside a showcase is one of the characteristics that should be known when purchasing a showcase. A method to define this property should be internationally standardised and the showcase should be labelled with appropriate indexes indicating its damping capability.

A possible method is to define an index such as thermal damping (TD), i.e. the variation of the internal temperature in response to an external variation, measured in the centre of the showcase. Under an external variation in the form of a square wave (e.g. the showcase is moved from an ambient to another ambient with a different temperature which departs by ΔT_{out}), the normalised change (NC) of the inside temperature, $\mathrm{NC} = \Delta T_{\mathrm{in}}(t)/\Delta T_{\mathrm{out}}$, is monitored during the course of the time t. The TD is then defined as a function of NC, e.g. by means of the slope (i.e. dNC/dt) between some stated values of NC, or by means of the time intervals needed to reach these values.

3.2. Greenhouse effect inside showcases

The well known greenhouse effect occurs when the solar radiation crosses the panes transparent to the visible light, interacts with the materials inside and part of it is dissipated via infrared radiation (IR). The panes are made of a material which is not fully transparent to the IR. A fraction of the IR, either incoming or outgoing, is absorbed by panes and is ultimately transformed into heat raising the ambient temperature. The greenhouse effect of a showcase is enhanced if the light is associated with abundant IR, as in the case of incandescence lamps. The IR income is partly absorbed by the panes, heating them; part of the fraction which penetrates into the showcase is absorbed again when tends to escape, further warming the panes.

In the case of the direct solar radiation (emission at ca. 6000 K) almost 99% of the power is concentrated in the so-called short wavelengths λ from 0.15 to 4.0 μm; 9% is in the ultraviolet (UV), 45% in the visible ($0.4 < \lambda < 0.74$ μm) and 46% in the IR [8–10]. For this reason the visible radiation contributes as much as the IR to the total heating effect of a greenhouse. In the case of an incandescence lamp, the source has a temperature much lower than the Sun and most of its power is concentrated in the IR. The lower the source temperature, the greater is the proportion of the IR band, according to the Wien displacement law. For instance, a tungsten incandescence lamp has a colour temperature ca. 2850 K and the power emitted is 10% in the visible band and 90% in the IR [11]. Therefore, for an incandescent lamp, the contribution of the visible band to the greenhouse heating is modest compared with the IR.

It is popularly claimed that glass is relatively opaque to the IR radiation, and that more appropriate are Plexiglas (i.e. polymethylmethacrylate), polycarbonate, polyethylene, polypropylene. However, for all these materials the transmittance in the IR band is neither 1 nor homogeneous, but is generally good except for some narrow absorption bands [12–14] whose relevance changes with the intensity of the spectral band of the IR radiation having the same specific wavelength.

Some laboratory tests were conducted on identical showcases, sized $20\times10\times10\ \mathrm{cm}^3$, with 5 mm thick panes made of glass, Plexiglas and polycarbonate, with a black sheet of paper in the bottom to transform all the visible radiation into IR. With a tungsten incandescence lamp, supplying 500 lx on top of the boxes, after 6 h the following overheating ΔT was measured in the centre of the case, i.e. glass pane: $\Delta T = 3.5^\circ\mathrm{C}$, Plexiglas and polycarbonate: $\Delta T = 2.9^\circ\mathrm{C}$. This experiment clearly showed that, in the case of external lighting with incandescence lamps, the Plexiglas is slightly better than glass, and Plexiglas has a response very close to polycarbonate. In practice, the materials more commonly used for panes, and having the same thickness, produce more or less the same greenhouse effect.

It is however possible to reduce the sharp rise of temperature working with the pane thickness. Making twice the pane thickness, initially the air temperature inside the case grows at a lower rate because of the greater portion of the IR that is absorbed and accumulated in the pane; after some 2 h the heat initially subtracted and accumulated in the pane penetrates inside warming the air to a slightly greater extent. After some 6 h, the overheating for Plexiglas with double thickness is $\Delta T = 3.1^\circ\mathrm{C}$, i.e. only 0.2°C more than the box having panes with regular thickness. In the long run, it is more advantageous to use showcases with thick walls because the internal heating is more gradual and the final overheating, compared with panes made of the same material but having thinner thickness, is very small or negligible.

However, in order to avoid dangerous heating and cooling cycles to exhibits, it is advisable to solve the problems paying more attention to the light source than to the pane composition or thickness. It is crucial to avoid lamps that have a great IR emission (e.g. tungsten incandescence or halogen lamps) because the direct contribution of the IR is dominant with reference to the absorption of the visible.

In another example, in the Museo Civico, Padova, Egyptian sarcophagi are conserved in showcases sized $1\times1\times2\ \mathrm{m}^3$. The sarcophagi are made of wood and painted with mineral colours on all sides. The showcases have glass panes, not airtight, and are illuminated by means of external incandescence lamps, turned on and off according to business time. During the summer, the room temperature had a daily span of 1.5–2°C, while inside the showcase the span was 4°C (Fig. 4). When the museum was closed and the spot lights were off, the temperature was the same inside and outside the showcase and the difference between the maximum and the minimum values remained within ±0.5°C. When the light was switched on, the temperature inside rose following closely the general law $T = 1 - \mathrm{e}^{-kt}$ (where k is the constant and t is the time), i.e. with a rapid increase at the beginning and eventually approaching an equilibrium determined by the radiative forcing and the heat dissipated through the glass panes and the leakage through fissures. At the closing time, when lights were switched off, the inside temperature, which was at its maximum, started to drop, and a few hours later the inside temperature equalled the room temperature.

To avoid the above problems, cold lights can be used. Fluorescent lamps are popular in this respect. Cold light can be obtained also with more pleasant halogen lamps filtering the IR (and the UV) wavelengths with glass optical fibres, and leaving the light source away from the case [15] with the advantage of having a better distributed spectrum.

The same laboratory experiment discussed above, i.e. lighting a showcase with 500 lx, but generated with a fluorescent lamp, led to no detectable overheating (i.e. within ±0.1°C). This confirms that the heating found in cases lighted with external incandescence lamps is mainly due to the absorption of the IR component and shows that the contribution of the visible band to the greenhouse effect is negligible (i.e. below the experimental threshold) at the lighting intensities used in museums. Although fluorescent lamps could be easily shielded against their harmful UV emission, they are not popular for their irregular

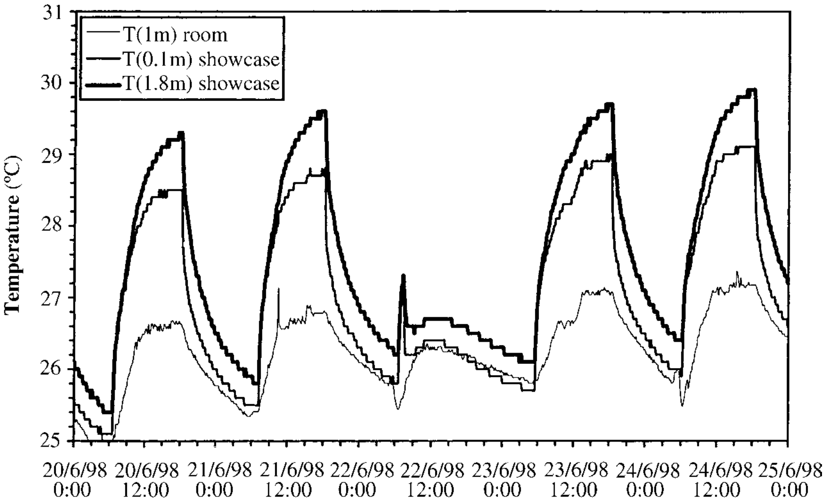

Fig. 4. Temperature daily cycles inside and outside a glass showcase at the Museo Civico, Padova, Belzoni Room. External incandescence lamps cause a sudden and strong internal heating for the greenhouse effect.

spectrum which gives poor colour rendering [16]. However, field tests performed in museums with showcases illuminated with fluorescent lamps showed an unexpectedly high internal heating. The reason was that the manufacturer placed the electric transformer inside the case, entrapping all its dissipated heat.

A combination of the above problems can be often found. An example is given of the showcase of archaeological (Paleovenetian) pottery in the Museo Civico, Padova. The showcase ($4\times1.5\times2.3\ \mathrm{m}^3$) is built with metal frame and glass panes, not airtight and is illuminated both with external incandescent lamps and internal fluorescence tubes. The result is similar to the example shown in Fig. 4, but the effect is enhanced by the heat dissipated inside. The temperature increases by $\Delta T = 10°\mathrm{C}$ on the upper part of the case, reaching a temperature above 40°C in the summer (Fig. 5). These large temperature cycles occurring every day (except on days of closure) work against the durability of the archaeological remains, especially on the glue used in restoration, so that the museum restorers had to intervene frequently to repair these artefacts.

It should be useful that every showcase has a quantitative index to show its characteristics in terms of IR absorption and greenhouse effect (GE). The class of GE can be assessed in the laboratory, in terms of the increase in temperature $\Delta T(t)$ observed in the centre of the showcase when it is lighted with a reference light source (e.g. halogen lamp), which gives a definite illuminance on a grey standard surface with known adsorption (e.g. Kodak Grey Cards with reflectance of 18±1%) placed inside the showcase.

It is evident that, in terms of conservation, the same goal can be obtained in different ways: using an incandescence lamp and avoid the rise of the inside temperature using a high GE quality showcase, or simply avoid the problem using a low or medium GE quality showcase, but a low IR emission light source (e.g. fluorescent lamp or a fibre glass), which is less expensive. The indication of the GE quality may help to find the appropriate combination of exhibit needs, light spectrum, pane composition and thickness, and cost.

3.3. Humidity variations inside showcases

In a closed environment with no vapour exchanges or phase changes, any change in temperature determines a relative humidity variation which is predicted by the thermodynamics. For example the effect of the temperature rise shown in Fig. 5 (which reached 10°C) led to a 20–30% drop on RH every day (Fig. 6). For this reason, when showcases contain artefacts sensible to RH variations, buffering agents are employed to smooth abrupt RH changes [17,18]. The most popular

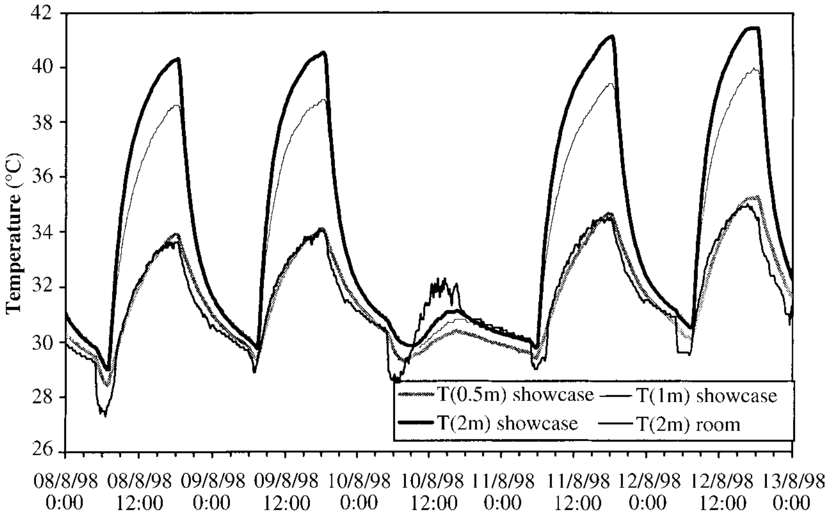

Fig. 5. Temperature daily cycles inside and outside a glass showcase at the Museo Civico, Padova, Paleovenetian Room. The overheating is due to two main factors: (i) greenhouse effect due to external incandescence lamps; (ii) internal heat dissipation of electric transformers for fluorescent lamps.

one is the silica gel, characterised by many fine pores and therefore extremely adsorbent [19], but 20 kg/m^3 of air are needed [1]. Of course, the whole mass of the buffer should be well in contact with the air, which makes unrealistic a very effective buffering for large buffer amounts. It might be useful to remember that, in the case of a buffer placed in a column below a showcase, but having only a small surface in contact with the case atmosphere, only a small slab of buffering material close to the exchange surface is active, and the silica located in the deeper layers remains inactive.

For example, limiting the ratio suggested by Thomson to a more realistic figure of 8 kg/m^3 of air (e.g.

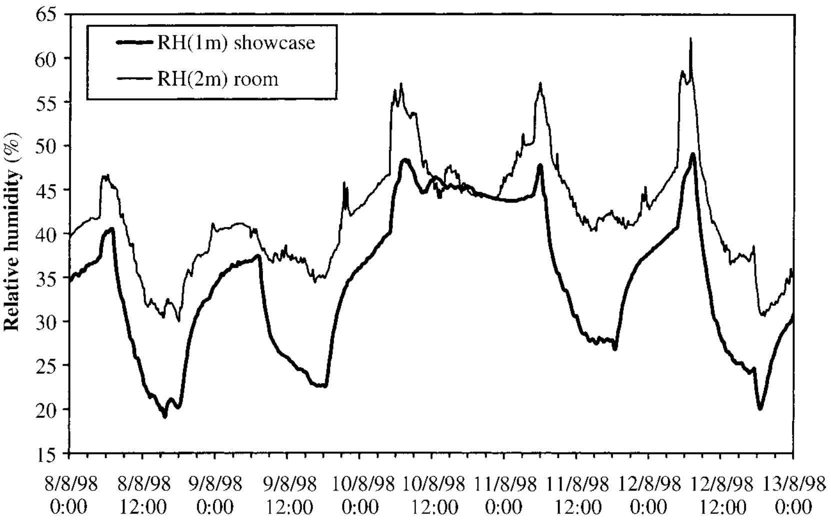

Fig. 6. Relative humidity daily cycles inside and outside the same showcase as in Fig. 5, Museo Civico, Padova. Inside RH changes are driven by temperature variations.

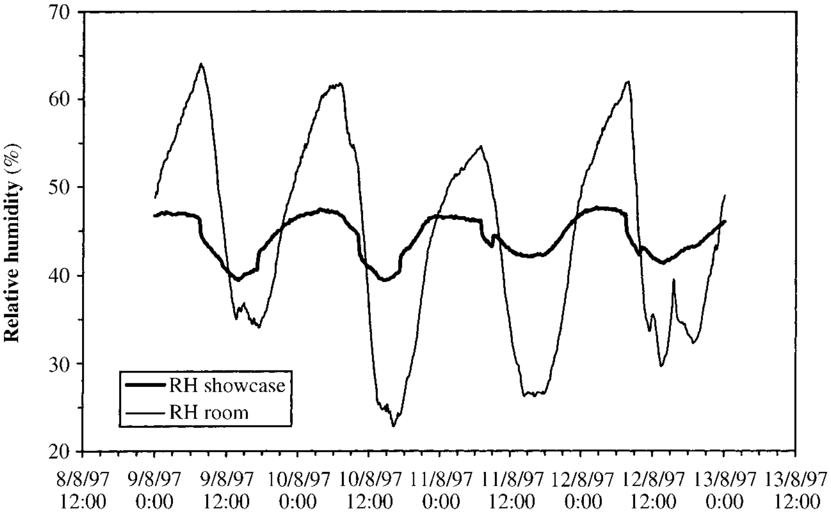

Fig. 7. Relative humidity daily cycles inside and outside the same showcase as in Fig. 3, the Sainsbury Centre for Visual Arts, Norwich. Incomplete RH buffering is obtained with insufficient silica gel absorption.

Sainsbury Centre for Visual Arts in Norwich, shown in Fig. 3), a 10°C daily temperature span determined 30–40% RH variation in the exhibition room which was limited to 10% inside the showcase (Fig. 7). How silica gel operates is evident in Fig. 8: the moisture concentration in air (i.e. the SH) varied with a daily span of 5 g/kg, for moisture released or absorbed to counteract the temperature influence on RH, which was not completely compensated for the insufficient amount of the buffering material.

Sometimes, it is not necessary to use silica gel, because the material of which the case is made (e.g. wood, wool, cotton, leather, parchment, paper) has good buffering properties. For example, in the showcase analysed in the Uffizi Gallery in Florence, the air volume is very small (about 0.03 m^3) and the wood

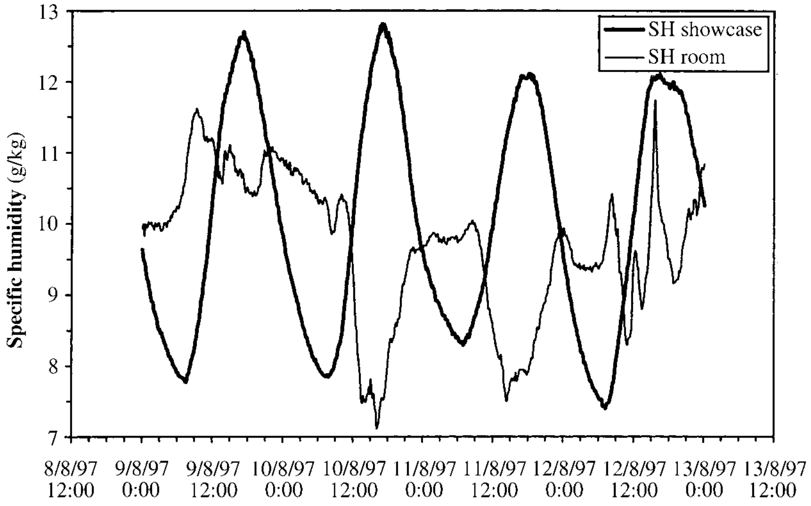

Fig. 8. Specific humidity daily cycles inside and outside the same showcase as in Figs. 3 and 7, Sainsbury Centre for Visual Arts, Norwich. Silica gel adsorbs and desorbs great quantities of water vapour, changing the SH inside the showcase, in order to stabilise RH, under the temperature changes shown in Fig. 3.

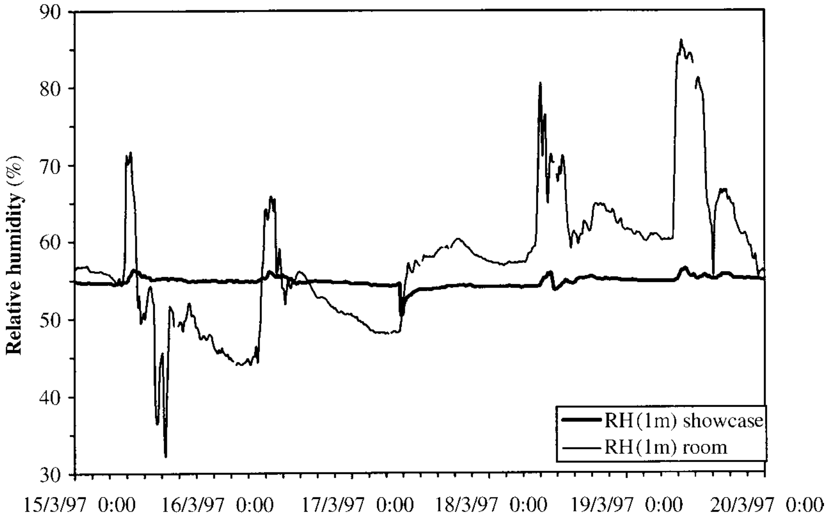

Fig. 9. Relative humidity daily cycles inside and outside the same showcase as in Fig. 1, Uffizi Gallery, Florence. Only modest RH changes occur in the small air volume.

and the tissue that form the bottom of the case are sufficient to keep RH changes within 5% (Fig. 9) in the case of the temperature changes shown in Fig. 1.

Of course, when in the air the RH changes, in the wood the equilibrium moisture content (EMC, i.e. the moisture content of the wood in equilibrium with the ambient) changes and wood emits or adsorbs moisture to reach a new equilibrium. This is true not only for naturally buffering wood frames, but also for artworks made of wood. This was observed in the above showcase displaying the Egyptian wooden sarcophagi. No buffering material was used in the showcase, whose internal temperature was changed by the lighting system as seen in Fig. 4, and the difference between the observed and the calculated RH should be ascribed to exchanges of moisture released/absorbed by the exhibit. For example, in the case of June 18 (Fig. 10) a span of 6% RH was observed, while 14% was calculated. This means that 5 g of water were alternatively adsorbed and released every day by each sarcophagus. These continual cycles of EMC cause expansions, shrinking and contractions, which are in the long run a cause of decay.

The moisture buffering properties of showcases can be quantified with an index able to describe the hygrometric buffering capacity (HBC) which ultimately represents the amount of water that can be absorbed or released by some buffering material. The definition of such an index is a complex task for it is not possible to consider the HBC as a ratio between internal and external RH variations in a way similar to the TD previously defined. In fact, the RH constancy requires the constancy (or an unrealistically complex combination) of two independent variables, i.e. T and SH. It is now necessary to define the response of a showcase in terms of a variation of T alone, or SH alone, which will produce the same effect on RH, and that should be compensated by some internal buffering.

In the case of an airtight, sealed showcase (i.e. with no exchanges of air and moisture between the case and the room), initially in equilibrium with certain T and RH values in the middle of the psychrometric chart, the HBC can be defined observing the actual departure of the inside RH as a consequence of a drop of temperature which would bring the inside atmosphere near to saturation in the case of non-buffered conditions. The smaller the actual RH departure, the higher the HBC quality. In principle, the definition based on a T change is a realistic representation of what may happen in any museum, and is equivalent to define the absorption of a certain quantity of vapour (e.g. which is necessary to absorb to compensate for a certain increase of SH) which leads to the same rise of RH in isothermal conditions, but that is less realistic for a sealed showcase. Once fixed the RH departures which

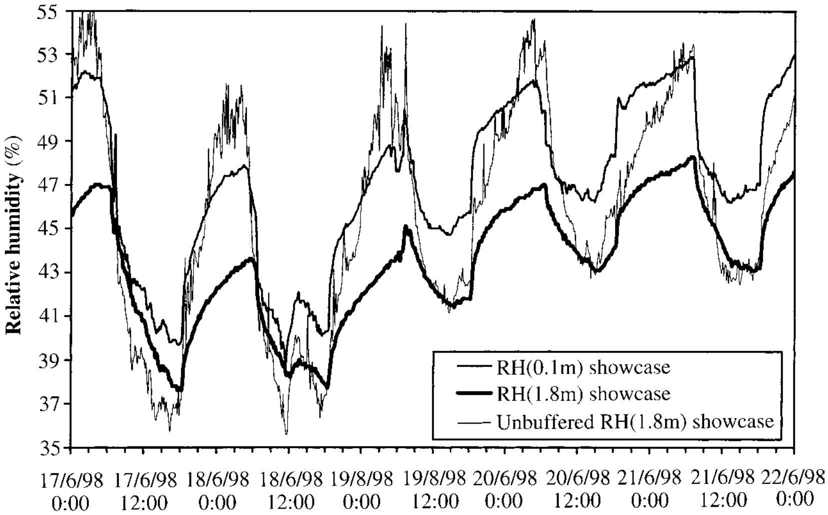

Fig. 10. Relative humidity daily cycles inside and outside the same showcase as in Fig. 4, Museo Civico, Padova. The wooden Egyptian sarcophagi adsorb and desorb water vapour responding to RH changes and are the cause of the difference between the observed and the calculated RH variations.

characterise every quality class, also the maximum amount of water (MAW) which will be absorbed by the buffer for every class, will be known. For instance, the amount of water (AW) that must be absorbed to keep constant the RH, i.e. to compensate for a drop of temperature which would bring from the initial values $T = 25°\mathrm{C}$ and $\mathrm{RH} = 50\%$ to $T = 15°\mathrm{C}$ and $\mathrm{RH} = 94\%$, is $\mathrm{AW} = 3.83\,\mathrm{g\ H_2O/m^3}$.

For non-airtight showcases, the vapour penetrating or leaking with the air exchanges, will be controlled with a more abundant (or more effective) buffering material, and the buffering capacity should be dimensioned to compensate the combined effect of both the external T and/or SH changes and the flux of air leaking through fissures. The inside/outside exchange rate can be expressed in terms of number of changes of air volumes per day (CVD). The quality class of a non-airtight showcase can be expressed in terms of the total amount of vapour that will be absorbed in a day to compensate for the inside RH change, and per every class it will be calculated as MAW(CVD+1), where the MAW are the values previously defined for an airtight showcase. The CVD index can be defined with standard methods used to measure air exchanges, e.g. the inverse of the time required to half the concentration of a trace gas (e.g. SF_6) inside the showcase.

The bulk HBC of a showcase is based on AW which is an index irrespective of the time needed to absorb or release water vapour. However, in the case of a rapid change in ambient temperature (e.g. opening windows for morning cleaning) it is also useful to define the buffering rate. This may be represented as the time needed for the sorption of half of the vapour that will be absorbed in the above fundamental transition, i.e. from the centre of the psychrometric chart to saturation, and the different classes of quality will correspond to fractions of this value.

3.4. Chemical and microbiological pollution inside cases

Microclimate influences both the deposition rates and the exchanges of air. When a case is not airtight, and fissures are present between the glass panes, airborne particles can penetrate and their inside concentration depends on several factors: the room particle concentration, the exchange of air (CVD) which is governed by the room air turbulence and advection, and the inside temperature cycle compared with the room one. In fact, when the case warms, e.g. for the heat generated by the lighting system, the inside air expands and some of it escapes outside. At night when

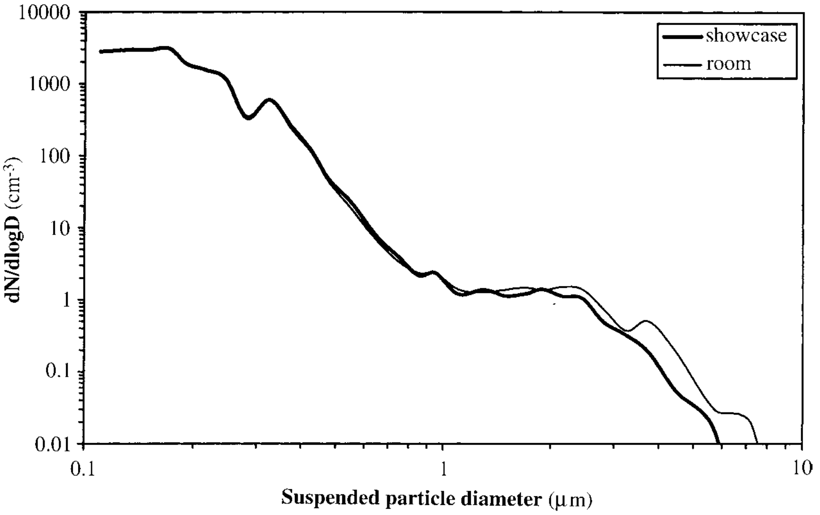

Fig. 11. Instantaneous distribution of suspended particulate matter as a function of particle diameter: comparison between distribution inside and outside the showcase at the Museo Civico, Padova, Paleovenetian Room.

lights are off and the case returns to the ambient temperature, the internal air contracts, thus sucking new air from outside with a breathing cycle which, in general, is less important than other mechanisms. For instance, the air exchanged every day through this mechanism in the showcase with the largest breathing cycle in the Museo Civico in Padova, was measured to be 0.4 m^3 per day, i.e. some 3% of the case volume.

The suspended particulate matter can be defined in terms of the spectral distribution density, dividing the particle size interval from 0.1 to 10 µm into 32 size classes and counting how many suspended particles belong to each class. A comparison between the particle spectral distribution densities inside the showcase and in the room (Fig. 11), shows that in the range of fine and medium particles up to 2 µm, departures are increasing with size, but remain limited within 20%; on the other hand, for large and coarse particles the departure tends to rapidly increase reaching 100% at 9 µm. This is due because inside the showcase, which has still air, the gravitational settling operates a depletion for particles with diameter greater than 2 µm which have settling velocity greater than 1.3×10^{-2} cm s^{-1} (for unit density particles), whereas in the room they are resuspended by turbulent motions.

The fact of finding a smaller concentration of coarse particles suspended inside a non-airtight showcase is not a proof of protection efficiency against dust, but only the consequence that dust has quickly deposited in still air, and accumulates inside, proportionally to the CVD.

Airtight showcases that offer a barrier to external air, protect exhibits from dust and other particle deposition. However, it would be inappropriate to conclude that airtight showcases are always preferable, because they entrap and accumulate a corrosive out-gassing made of VOC released by materials (e.g. wood, glues or varnishes coating) of which the cases are made, provoking damage to exhibits. In addition, being shielded against ventilation, they provide a habitat favourable to the colonisation and growth of micro-organisms. Although microclimate variations and atmospheric pollution are generally recognised as important factors in the deterioration of cultural properties, biodeterioration deserves more attention that it has received. In fact, a great number of micro-organisms colonising a variety of materials located in urban environments have been recorded [20]. They can be found both on and beneath surfaces. However, the interactions between VOC and micro-organisms, the use of organic pollutants as nutrients, the studies on different inputs or organic matter to different materials, etc. have rarely been investigated [21].

Showcases with forced ventilation do not meet the aim of smoothing out room temperature fluctuations, but reduce the development of bacteria [22]. Not sealed showcases have uncontrolled air leakage which transports inside undesired dust and pollution. A closed showcase without ventilation furnishes a suitable habitat for bio-organisms which grow undisturbed and infect the works of art inside. Controlled and filtered ventilation is a recommendable solution against microbiological growth as biocides should be avoided for they are dangerous for human health and may contaminate the ambient.

4. Conclusions

Showcases are important to preserve and protect delicate works of art against environmental risk factors. However, actual showcases present a number of drawbacks, which not always can be completely eliminated: often solving a particular problem, another new problem is generated. In practice, the best showcase is the case which does not present major inconveniences for the specific artworks to exhibit, or that does not create particularly dangerous synergisms for these exhibits.

The most commonly used panes, made of glass, Plexiglas (i.e. polymethylmethacrylate), polycarbonate, polyethylene and polypropylene, are not fully transparent to IR (all of these materials have a similar IR absorption) and transform a showcase into a greenhouse. At the low lighting intensity used in museums, the contribution of the visible band to the greenhouse effect is very modest or negligible and the overheating is mainly due to the IR band emitted by the light source. Incandescence lighting systems cause internal overheating, changes in relative humidity and internal air mixing driven by thermal gradients; in turn, the internal air movements increase the deposition rate of suspended particles entrapped in the case. For these reasons light sources should always be placed outside the case. Most of the above problems can be eliminated with cold light, obtained with filters, fluorescent lamps or using fibreglass light guides which can cut-off dangerous IR or UV wavelengths. Attention should be paid to the position of the light source and the electric transformer, e.g. external to the case and possibly over the top in order to avoid case overheating, that in the above case study reached $\Delta T = 10°\mathrm{C}$. The light damage is cumulative and the most delicate objects should be lighted only when visitors are in front of the showcase, using proximity sensors.

The inside temperature and relative humidity should be constant, but they are continually variable for a number of reasons, e.g. external temperature change and conductivity across the structure (especially when it is made of metal) or the pane; greenhouse effect; radiation directly falling on exhibits which may overheat or release/absorb moisture; insufficient buffering or too low buffering rate. Also the thermal (or humidity) damping can be improved with a suitable use of construction materials which increase the thermal (humidity) inertia, and the most useful advantage is the cut-off of the short period fluctuations.

Non-airtight showcases allow the sorption of pollutants, the penetration and the sticking of dust particles, which deposit especially via gravitational settling. Airtight showcases furnish a habitat favourable for the microbiological colonisation and growth of microbes. Showcase are often built with materials which are not inert, with off-gassing and release of VOC. These corrosive substances are accumulated inside the showcases (especially in the airtight ones) which risk to become the most polluted site within the museum.

In practice, every showcase is characterised by a different response to the environmental forcing. These features, and their synergistic combination, may constitute an advantage or a disadvantage according with the nature of the exhibit and the aim of the conservator. It would be useful if all of these characteristics and the response to the ambient were indicated with internationally agreed indexes, which represent the level of quality in view of the specific problems of the user. This indexing would allow the best choice of a showcase in view of the conservation requirements and in comparison with the most reasonable cost. This paper suggests some indexes and how to arrive at a quantitative evaluation of their quality level.

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