Problem-zone "Window"

Alfons Huber

Summary

During the period of redevelopment of many museums in Austria and Germany in the last two decades, much emphasis was laid on the improvements of house technique as well as on reducing energy losses in winter. The latter was done sometimes by replacing the traditional double-pane chest windows with single casement windows with insulation glass. But the double-pane chest window is an intelligently developed part of historical museum buildings. If properly repaired, sealed and maintained, and then retrofitted with a physically adequate shading system, such windows are the perfect solution to the opposite climatic stresses of winter and summer.

One of the unexpected consequences of these refurbishments, however, is the fact that sun-exposed (but unsuitably) shaded windows, together with the exhibition lighting, *considerably increase* the indoor temperature in summer. We could quite often observe the same problems under sky-light roofs after the original green coloured glasses were replaced with translucent insulation glass panes.

In this paper I will illustrate that through an improperly adapted chest window, the surface temperature of the inner glass pane can rise above 60°C. On the other hand, it is possible to reduce the surface temperature of the same sun-exposed window down to 31°C at most, only by means of an adequate arrangement of different sheets, coated panes and through natural ventilation of the window chest.

With a physically adequate shading system and a variable lightning concept, the running costs of an exhibition in summer can be reduced to a factor of ≥3.

Physical mechanisms

Although the physical mechanisms and their impacts are very simple, I have observed with growing astonishment over 20 years, that in my sphere of activity, they are ignored or neglected by most architects, curators and museums managers.

The sun emits a wide spectrum of electromagnetic radiation, and a significant part of it generates thermal effects on the indoor climate of a building. The invisible, mainly thermal effective IR-wavelengths from the sun extends from 780nm to about 2000nm. The visible part of daylight (400 – 780nm) is also radiant energy that can be converted into heat through absorption. The invisible short-wave UV-section, below 325nm, is almost fully filtered out by the glass panes of the window.

Whereas the short-wave UV region mainly causes damage such as fading or degradation of organic materials, the long-wave IR region brings about heating of the entire indoor environment, causing dehydration and damages of shrinkage of all organic materials.

When solar radiation meets a window pane, part of it is reflected, depending on the angle of incidence, a small part gets absorbed by the glass and is released to the environment as thermal radiation. The further behaviour of the remaining radiation will depend on what is behind the pane. The type of window – chest window, one-casement window, compound window – as well as the kind of sun protection devices, will have a direct impact on the thermal behaviour of the window.

Following the oil-shock of the 1970s, new types of window with insulation glass became favoured. On the one hand, the physicists aimed at decreasing the thermal flow through the window to reduce energy losses in winter (insulation glasses). On the other hand, laminated glasses were developed that were either coated with extremely thin layers of metal to reflect most of the IR-region of the spectrum and/or tinted to reduce the transmission of radiation in general (sun protection glasses). The latter are often used by modern architects for sun-exposed buildings with huge glass facades, but are unusual in historical buildings.

The key to understanding the problem of increasing indoor-temperature caused by sun radiation is simple: Most of the light radiation is finally transformed into heat through absorption. Thus three principles must be observed:

1) The positioning of the first plane of absorption is of essential importance – it emits the highest amount of thermal radiation. From a sun protection system mounted in the middle of a window chest,

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Figure 1. The Collection of Antique Musical Instruments (SAM) is located on the second floor of the Neue Burg. Its 22 windows face the south-east.

Figure 2. Sun protection measures in the windows of the Collection of Antique Musical Instruments.

about 12% of the absorbed energy emits into the indoor environment. The same equipment, however, mounted inside the room, behind a one-casement window, emits 27% of the absorbed energy.

2) The heat-flow of the absorbed energy must be hindered from reaching the indoor environment.

3) If radiation is absorbed by sun protection devices mounted in front of a one-casement window (outdoor) or between the panes of a chest-window, then part of the absorbed heat can quite easily be ventilated off through convection. If radiation is absorbed by the solid walls or by the indoor equipment of the building – for lack of or ineffective sun protection equipment –then either the indoor temperature will increase significantly, or you will need an air-conditioning system, resulting in significantly higher costs for technical cooling.

Conditions in the collection of antique musical instruments

The Sammlung alter Musikinstrumente (SAM, Collection of Antique Musical Instruments) of the Kunsthistorisches Museum in Vienna, the oldest and one of the most important collections of its kind, is located since 1965 on the second floor of the Neue Burg, with 22 big chest-windows (each around 3.7m^2) facing the south-east (fig.1). Semi-transparent sun protection foils, mounted inside the exhibition rooms, brought about surface temperatures up to 40°C and indoor temperatures rising up to 30°C in summer. Because of extreme climatic problems also in winter, and therefore serious damage on almost all objects made of organic materials, the collection had to be closed and refurbished between 1988 and 1991/93. In consideration of the facts and problems mentioned above, a sophisticated sun protection concept was developed after three years of measuring, observing and comparing. The physically most effective solution – an outer shading system – was forbidden due to the cultural heritage status of the building. All windows were thus equipped *within* the chest space as follows (fig. 2):

1) A roller blind, made out of close-woven linen/ cotton was fixed just behind the outer pane (first plane of absorption).

2) A zigzag-folded aluminium-coated sheet of polyester, (57% reflection, and 6% transmission) was mounted in the middle of the window-chest and motor-operated.

3) A silver-coated foil of polyurethane (85% reflection) was mounted next to the inner pane.

4) The window space was ventilated diagonally through a slot in the windowsill and through the opened outer flap of the fanlight (both are shut in winter).

5) The heat-flow from the window into the room, caused by the absorption on the sun protection devices, was minimized by a so-called "3rd pane"– a glass pane mounted in a wooden frame like an additional casement window and screwed tightly to the inner window frame, thus reducing the U-value by 25 to 30% [1].

Through this, it was possible to lower the surface temperature of the inner pane by a value exceeding

10K. Feeling relieved, I anticipated the reopening of the collection.

It was really a shock when, in August 1993, the indoor temperature rose above 31°C – this was even more than before closing the collection to the public! How could that be possible? The answer proved to be very simple.

In 1994, my proposal "Vergleichende Untersuchungen von Heizungs- und Klimasystemen in Museen und Schlössern" (Comparative Studies on Heating and Air-conditioning Systems in Museums and Castles), was accepted by the jury and finally became the EuroCare-Project EU-1383 "Prevent" under the direction of Wolfgang Kippes of Schloss Schönbrunn. The investigation of the windows of the SAM, entitled "The optimal museum's window", became a part of the "Prevent"-project [2].

For three years the heat-flows were measured in two sun-exposed chest windows of the Neue Burg, equipped with different sun protection systems. The target of the investigations was on one hand, to look for the most effective sun protection devices, and on the other hand, to find out the cause for the increase of indoor temperature.

The result of the project was as follows:

As the lighting concept was changed from daylight to artificial lighting of the exhibition rooms and show cases, a considerable amount of electric energy had to be installed.

This leads to the conclusion that because of the inefficiency of lamps in comparison with daylight, relatively more electric energy is needed to compensate for the missing daylight [3]. The waste heat resulting from the lighting on top of the remaining heat flow from sun radiation through windows and walls, leads to a considerable increase of indoor temperature in summer (> 28°C). Installing more than 8 to 10 W/m2 of electricity requires an effective ventilation system or air-conditioning.

Outer shading and its evaluation

The EuroCare project EU-1383 "Prevent" has clearly shown that the present sun-protection equipment between the windows, combined with minimizing the lighting to 8-10 W/m^2, does not leave any more room for reduction of indoor-temperature. Further improvements could be obtained only by shading systems mounted outside the window, and improved ventilation.

As the Neue Burg is an historical building of cultural heritage, only an "invisible" system was conceivable. The first idea was to decrease the sun radiation input by decreasing the open plane of the window by means of fine-meshed wire nets or expanded metal screens. One of the parameters of such nets is the "open plane" *Ao*, defining the open space between the wires of the fabric or the bridges of the grill respectively. The idea was that a screen with an open plane of 50% halves the radiation input. So several woven wire nets of stainless steel with different mesh-widths were tested and compared with different expanded metals.

To compare several sun-protection materials simultaneously, four boxes (40 x 40 x 7cm) were made with a bottom of 5mm plywood covered with black paper that served as a radiation absorber. The temperature of the bottom was defined as a measure of the input of sun radiation into the exhibition rooms. The boxes were equipped with the different nets and screens in combination with normal float glass, insulation glass and shade-lite sun-protection glass. The behaviour of a chest window could be simulated with a second frame, put on the glass-covered box.

The development of the temperature of each box was monitored by a Pt-100 sensor. Normally, one of the four boxes, covered with a single float glass pane, was left unprotected as a reference for a window without any shading system (blue curve in fig. 3). Note the significant decrease of radiation input with the expanded metal (red curve) from about 10:45 a.m. onwards because of the geometrical structure of the screen. The net with Ao 22% in these first tests obviously showed the best results (black curve in fig. 3).

Surprisingly however, the measurements had shown that with the decreasing angle of incidence of the

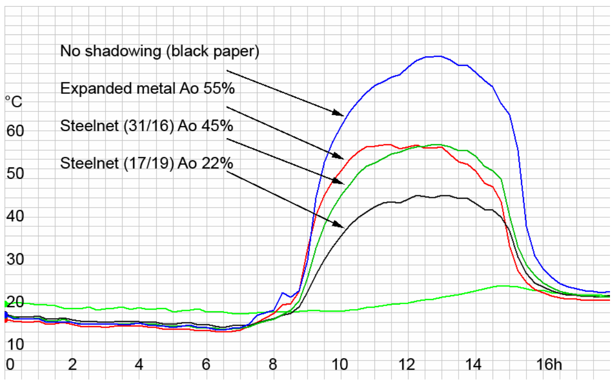

Figure 3. Comparative measurements of metal nets Ao 44% and Ao 22%, and expanded metal Ao 55%. Note the significant decrease of radiation input of the red curve (expanded metal) from about 10:45 onwards because of the geometrical structure of the expanded metal.

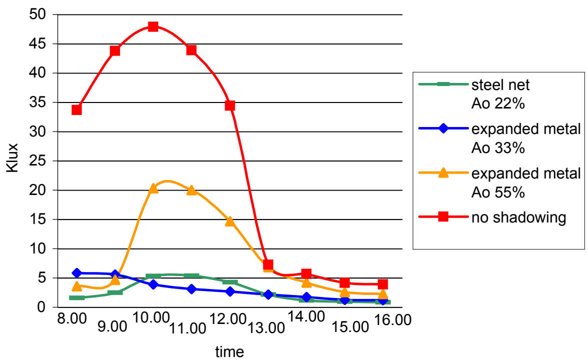

Figure 4. The efficiency of shading expressed as lighting intensity in Klux: Note the significant decrease of light transmission of the expanded metal Ao 33% from about 9:30 onwards.

rising sun, all woven metal nets reflect a considerable part of the radiation into the room, because each single wire serves as a cylindrical reflector. Because of its geometrical structure, the expanded metal turned out to be superior. The stainless steel net with Ao 22% showed worse results than the cheaper and more transparent extension metal with Ao 33%. Fig. 4 shows the different effects of shading of the steel net Ao 22%, expanded metal Ao 33% and expanded metal Ao 55% in comparison with the unshadowed window: In this measurement over one day, the light intensity, measured in Klux, served as an equivalent of the radiation input. It can be seen clearly, that the geometrical structure of the expanded metal Ao 33% causes a significant decrease of light transmission from about 9:00 a.m. onwards. Finally a composite frame combining a polycarbonate pane – coated with sun-protection foil – with an expanded metal screen with 33% Ao mounted behind the polycarbonate pane showed the most convincing results (see below).

After selecting the most effective varieties, prototype models were made for two windows in the exhibition rooms to compare simultaneously two variations of the proposed devices to find out the optimal system. In this case, the air temperature within the window chest was measured in both windows as well as the surface temperature on the inner glass pane [4].

Development of the improvement

To demonstrate the efficiency of the single measures, a series of measurements was carried through to show the development of the improvements step by step. The first reference standard was a shading system which was installed in large numbers during the refurbishment of many collections and museums in the 1990s: a single layer of the already mentioned aluminium-coated polyester fabric with 57% reflection and 6% transmission [5].

As meteorological circumstances changed during the experiments, all curves always must be read in their relationship to the reference standard. (In the following graphs the lower value gives the temperature of the inner glass pane, the higher value the temperature inside the window chest.)

1.) Fig. 5 shows in the left curve that a combination of a reflecting material (reference standard) with a non-reflecting material (linen/cotton roller blinds), mounted nearer to the outer pane, gives significantly better results. The right curve, however, shows that a third layer, although it is of a high quality (85 % reflection), causes no significant decrease of energy input [6].
2.) A significant improvement is the convective ventilation of the window chest (fig. 6). A simple solution is to fix the outer wings in a slightly open but rain-tight position. This reduces the thermal input of the window up to 25%. In our big balcony doors (~ 6m^2) a panel at the base of the outer wing was changed into a moveable flap which can be fixed open during the summer period. To support convective circulation a second flap can be opened at the top of the window.
3.) The third stage of improvement is to reduce the heat transmission of the inner glass pane. This can be easily achieved by mounting a second window leaf sealed onto either the inside or the outside of the inner window frame, reducing the convectional thermal transmission [7]. A more effective but also more expensive method is to replace the inner float-glass pane with an isolation glass pane. However, this is only possible if the construction of the leaf of the casement window is strong enough. Due to this measure the heat input of the window can be reduced by a further 25-30%.

Fig. 7 shows the partly optimized sun protection system of the SAM since 1991 (triple shading + ventilation of the window-chest + insulation of the inner pane) in comparison with the normal sun protection system. Further improvement is only possible through outside shading.

In the last series of measurements, variations of this partly optimized system became the new reference to investigate the effect of the outer shading systems. Fig. 8 shows a window with triple sun protection in the non-ventilated window-chest in comparison with a window with outer shading by an extension metal (Ao 33%) and triple shading in the ventilated window-chest. In Fig. 9 the outer shading is optimized by a polycarbonate pane covered with a silver-coated PU-foil (transmission 63%), combined with the extension metal Ao 33%; the window chest

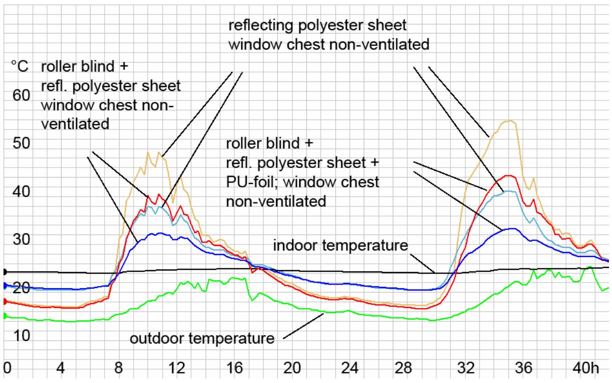

Figure 5. A combination of a non-reflecting and a reflecting shading system causes a significant improvement (left curve). A third layer of a high-reflecting PU-foil shows no significant effect.

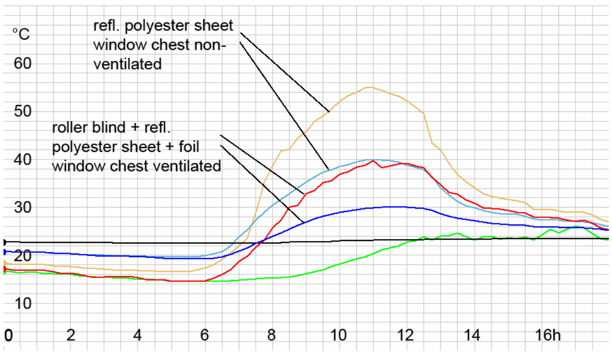

Figure 6. The ventilation of the window chest reduces the thermal input significantly

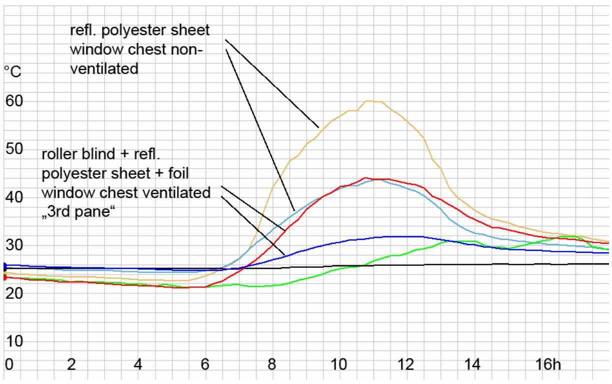

Figure 7. A "3rd pane" or insulation glass at the inner window wing reduces the heat flow from the window chest into the room by about 25%.

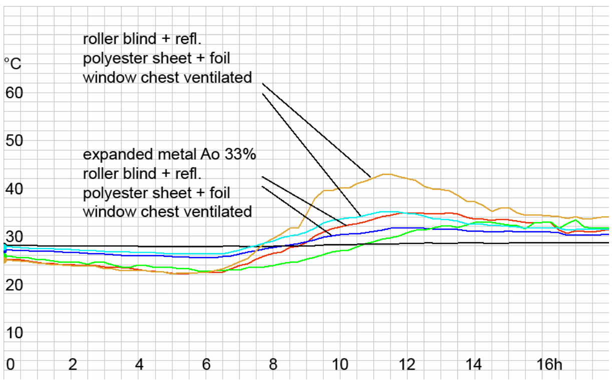

Figure 8. The improved shading system in comparison with outer shading by expanded metal screen Ao 33%.

with triple shading is ventilated. In this arrangement, the surface temperature of the inner pane reaches only 1,5K over indoor temperature.

The full efficiency of this outer shading system can be seen below in fig. 12: The temperature in the window chest of the conventionally treated window (67°C) is 35K higher than in the optimized window. The surface temperature of the inner pane of the optimized window (28°C) is 12K lower than the "normally" shaded window.

Other "Standards"

In the Kunsthistorisches Museum several different solutions of more or less succesfully working shading systems were installed in the past. To investigate the possibilities of improvement, some of them were simulated. The worst case is the shading of the "Bassano-Saal". The inner glass panes are covered with black paper – nothing else. This causes surface temperatures reaching more than 60°C (fig. 10). The energy input is compensated by a 4kW air-conditioning device.

In 1990 a controversial discussion took place in the KHM, whether insulation glasses in chest windows should be mounted at the inner or at the outer wing of the window. At least the structural physicist decided to replace the outer float glass pane of the windows of the picture gallery by a double insulation glass pane. In the meantime this decision was revised by experience: the thermal impact caused by absorption at the shading devices is prevented by the insulation panes from flowing to the outside and transmits into the exhibition rooms, which have to be cooled by air-conditioning, causing high running costs. Fig. 11 shows the situation in identically shaded chest windows with insulation panes mounted at the inner and outer wings respectively. A significant improvement is possible, but for this situation only through an outer shading: fig. 12 shows a simulation of the situation in the picture gallery in comparison with the improved sun protection of the musical instruments collection.

Although insulation glasses at the outer wing of a chest window is now accepted as physically wrong, this situation is still "state of the art" within sky-light roofs. The radiation input through the translucent insulation glasses into the roof is absorbed by walls and floors. The heat flows directly into the solid construction of the building, where it is stored by the mass of the brick. An improvement is possible only by two measures:

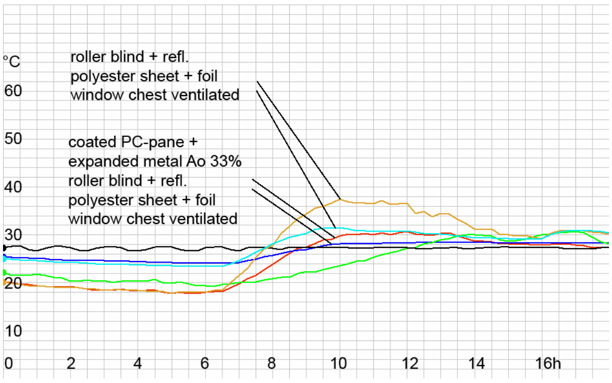

Figure 9. The optimized outer shading: Polycarbonate pane covered with silver-coated PU-foil combined with expanded metal screen Ao33%.

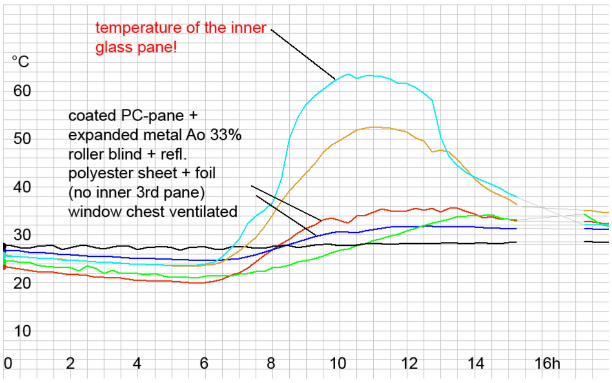

Figure 10. The worst shading system ever found in a museum: A chest window without any shading with the inner glass panes covered with black paper, causing surface temperatures higher than 60°.

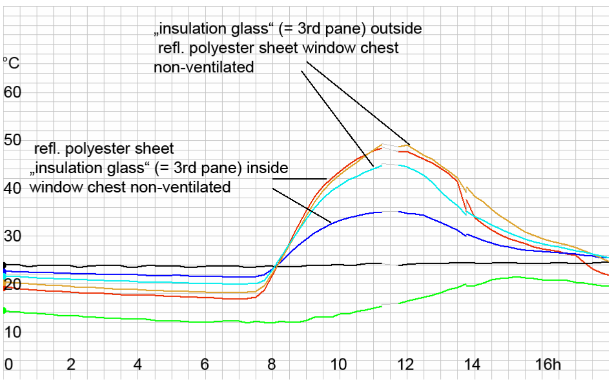

Figure 11. Windows with translucent outer insulation glasses and traditional shading systems cause a higher thermal input than windows with inner insulation glasses.

1. Outer shading or

2. Reduction of about 50-60% of the general transmission of radiation through tinted and metal-coated sun-protection foils applied to the outer glasses (first plane of absorption). An additional movable sun-blind has to be mounted directly under the glass roof to absorb most of the remaining radiation before it can reach the solid brick or concrete construction, from which it hardly can be removed by ventilation, whereas the

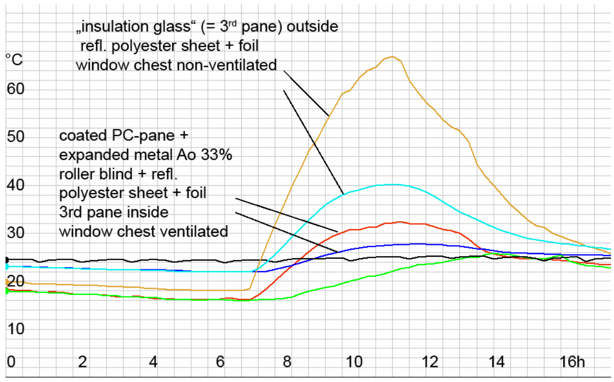

Figure 12. The temperature (67°C) in the window chest of the conventionally shaded window with outer insulation glass is 35K higher than in the optimized window. The surface temperature of the inner pane of the optimized window (28°C) is 12K lower than the "normally" shaded window.

Figure 13. During winter, the arches of the loggia of the Wiener Staatsoper are closed by a movable glass construction.

Figure 14. Eight windows of the main facade of the Wiener Burgtheater are covered up with big photographs of actors.

absorption heat between glass pane and sun-blinds can be ventilated off by convection more easily.

Figure 15. Twenty-six windows of the main facade of the Parliament are supplied with outer shading by means of plastic roller jalousies.

Figure 16. Prototype of the optimized outer shading (left) next to the situation since 1991 (middle) and a PC-pane without coating but with an expanded metal blind behind it, mounted in a frame in front of the window (right).

Aesthetic aspects

To my knowledge, in all traditional Austrian museums any outer sun-protection system - the only physically effective solution – has been forbidden so far with reference to the 'cultural heritage' status of the historical building. But until now I never understood why the mere historical appearance of the façade has to be protected more than the thousands of valuable objects contained therein. Meanwhile I know of several examples where the appearance of historical buildings has been changed – not for reasons of conservation but mostly for commercial ones. Needless to say that hardly any public objection was raised. Three prominent examples may be sufficient to mention:

1) During winter the arches of the loggia of the Wiener Staatsoper are closed by a movable glass construction to protect the visitors of the famous "Opernball" from outside temperatures (fig. 13).
2) Eight windows of the main façade of the Burgtheater are covered up with big photographs of actors (serving as an optimal sun protection for the stair-case and gallery, fig. 14).
3) Twenty-six windows of the main façade of the Parliament are supplied with outer shading by means of plastic roller jalousies to protect our representatives from over-heating (fig. 15).

In comparison with these examples, the proposal for the SAM looks very inconspicuous: Fig. 16 and 17 show the prototype of the optimized outer shading (left) next to the situation since 1991 (middle) and a PC-pane without coating but with an expanded metal blind behind it, mounted in a frame in front of the window (right). The frame has to be fixed in a distance of c. 20mm for cooling the pane by convection. Because of the high extension-factor of PC (0,07mm/°C/m) the pane has to be mounted "swimming" in the frame. It is important for an "invisible" construction that the frame holding the pane has the same colour as the window frame and that the inner contour of the shading frame follows the visible dimensions of the glass pane (without the putty rabbet), so that reflecting and non-reflecting parts, seen from below, show exactly the same dimensions as the other windows of the building without outer shading.

Conclusion

It is only a question of time before the waste of energy as well as of financial resources no longer will be accepted by the public. It is simply a nonsense to allow a building to be heated up by sun radiation impact and then to cool it down to "normal" conditions, requiring an enormous amount of energy, technical effort and expense. The proposed outer shading device reduces the input of sun radiation into a building in an inconspicuous and very effective way. With a physically adequate shading system and a variable lightning concept, the running costs of an exhibition in summer can be reduced to a factor of ≥ 3 [8].

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Figure 17. General view of the façade of the Neue Burg, seen from the Burggarten.

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2 Michael Kotterer, Henning Großeschmidt, Frederick P. Boody, Wolfgang Kippes (ed.), Klima in Museen und historischen Gebäuden: Die Temperierung. Wissenschaftliche Reihe Schönbrunn, vol. 9, Wien 2004. See also: http://www.khm.at/files/windows1.pdf (31.5.2007).
3 The luminosity of an incandescent lamp is ca. 15-20 lm/W, of a halogen bulb ca. 22-32 lm/W, of a fluorescent lamp 67-94 lm/W. The theoretical maximum of luminosity, the photometric radiation equivalent, is 683 lm/W. Günther S. Hilbert, Sammlungsgut in Sicherheit 2, Berlin 1987, 14-37.
4 The first sensor was mounted on a stick fixed behind the first screen (normally the linen roller blind or the polyester blind) and protected against direct radiation by an aluminium foil. The second sensor was mounted at the indoor-side of the inner pane and covered with a black foamed material serving as an absorber of the remaining radiation.
5 Verosol 312, Fa. Adler-Solux
6 With a double or triple shading system in a chest window, a high-reflecting material mounted first in the sun beam causes a higher energy input than mounted as the last layer, as the absorption heat of the second and third layer is reflected through the inner glass pane into the room.
7 The pane of this second window frame can be made of polycarbonate, which weighs half of the normal float-glass.
8 The Antikensammlung of the KHM, equipped since 2005 with new lightning and partial air-conditioning (80 kW/h for 1600 m2), needs about eight times the running costs of the Sammlung alter Musikinstrumente (10 kW/h for 1600m2). Nevertheless, because of its insufficient shading system and energy-intensive performance, in August 2006 the indoor temperature in the "cooled" Antikensammlung (30,5°C) exceeded that of the SAM (29,5°C).

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