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Optimizing environmental conditions for the preservation of rare books and illuminated manuscripts, including in exhibitions

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All man-made objects undergo changes during their lifetime, they age and at some time they may desintegrate. This process is unavoidable; it is caused by chemical reactions which take their course in the various materials of which an object is made. How fast these reactions, however, proceed depends on environmental factors such as climatic conditions, light and air pollution. It is not rare that we find historic and artistic works of about the same age, provenance and material composition in rather different states of preservation - depending on how (under which conditions) they have been kept. We may conclude, therefore, that optimizing environmental conditions is the most important measure to take for lengthening the life of rare books and illuminated manuscripts.

Temperature

As already mentioned the aging of materials is caused by chemical reactions in the materials themselves. Moreover, all chemical reactions are accelerated by a rise in temperature. In fact a rise in temperature of 10° at least doubles the rate of aging, however, it is very probable that the process is speeded up much more than twofold. In consequence of that basic chemical fact, the temperature in rooms where books and manuscripts are stored should be kept as low as possible. From the theoretical point of view, keeping rare books in a refrigeration chamber (cold storage room) might be desirable but is only seldom practicable. Apart from the high cost of running cold storage rooms, the objects would be rather stressed when they are taken out from time to time, due to the quick and drastic change of temperature and humidity, even dew may collect on the surface of the objects. It would be more realistic to look for rooms or a building which do not grow too warm inside even on hot summer days. Indoor temperatures can often be reduced by blinds, which, however, must be mounted on the outside. Although it might be difficult in some buildings to keep the temperature below 22° C during the warm season, it is easy to maintain a moderate temperature at least in winter by economical heating (maximum 16-18° C, if practicable also below). Saving heat in winter is advantageous for the relative humidity, too; it

requires less artificial humidification to maintain about 55 % relative humidity if the room temperature is kept rather low.

If the local climatic preconditions and/or the construction of the building do not permit keeping the rooms in which rare books are stored or exhibited at a moderate temperature of 22 - 23° C in summer (in spite of blinds etc.) an air cooling system should be installed. The librarian should bear in mind that an elevated temperature not only accelerates the material inherent degradation but also promotes the attack of light and air pollutants. It must be emphasized that the construction of a building (including window area, isolating properties of walls, masses of masonry, construction materials etc.) is decisive for the stability of its indoor climate. The best preconditions in this respect would be an underground building because the surrounding earth establishes the best ever thinkable heat insulation. A rather constant temperature also reduces fluctuations considerably in the relative humidity which might be harmful for rare books and manuscripts as we will explain below.

Relative Humidity

Parchment, paper, wood and leather are hygroscopic materials - they, therefore, always contain a certain amount of water. This water content is in equilibrium with the water content of the air (relative humidity). If the air becomes drier the material loses water or vice versa, if the relative humidity rises hygroscopic materials absorb additional water. This desorption or absorption process is connected with shrinkage and swelling, thus distortion may result.

In order to avoid stress and strain in books and manuscripts made of the above-mentioned materials, it is necessary to keep the relative humidity in their environment rather constant at a level of about 55 % - 60 %. The relative humidity should not exceed 65 % for more than a couple of days, because in consequence the objects may suffer from biological attack (mould growth). If the air is too dry, below 45 %, irreversible distortion of parchment and book covers can occur; leather and paper lose their strength and flexibility.

A fully air-conditioned building, of course, enables to maintain a relative humidity of about 55 % all over the year, as well as to keep a moderate temperature (not more than 22° - 23° C) in a hot summer. In many cases, however, libraries are not housed in a modern well air-conditioned building but often in historic buildings which cannot or should not be fully air-conditioned (because of unavoidable loss of historic substance). So we usually have to find a good compromise between the preservation of the historic building and establishing suitable climatic conditions for the objects. Often, however, historic buildings have good preconditions for a rather steady *natural* climate: big masses of masonry balance strong fluctuating temperatures between day and night. The window area is usually less than in modern buildings; in addition mounted blinds outside of

the windows can reduce a heating up of the interior. In every building there are rooms with varying climatic conditions due to their different location within the building, and it must be added that e.g. the size of the window areas as well as what direction the windows face play an important role. Therefore, the first step should be to find the rooms with the most balanced climate. For that reason relative humidity and temperature in the different rooms should be recorded by thermographs for at least one year.

Artificial humidification during the heating period

In the case of favourable climatic conditions inherent to a building respective to certain rooms one should at least try to equalize the difference in relative humidity between summer and winter (heating period). The deficit in relative humidity during the heating period is caused by a lower absolute humidity of the outside air on colder days. If this air with lower water content (absolute humidity) is heated up the relative humidity inside drops (fig. 1). Therefore, the lacking amount of water has to be added as vapour to the air in order to achieve a level of relative humidity which corresponds about to that after the heating period. That means humidifying will mainly be confined to the heating period. The percentage of relative humidity maintained artificially should be based on the average relative humidity in the warmer seasons. It is not advisable to establish theoretically better humidity during the heating period if this differs markedly from the warmer seasons.

Observations and experiments have shown that the man-made long-time seasonal differences between the heating period and warmer months cause much more damage than the short time-fluctuations of relative humidity which constantly occur due to the changes in outdoor climate. Summing up, the first and simplest measure to take in a suitable building is to balance the deficit of humidity during the heating period with (automatically controlled) humidifiers. In this case, the temperature is allowed to fluctuate and the objects are exposed to the naturally occurring short-time changes of relative humidity in the warmer seasons. Room temperature in winter should be kept as low as possible, also because of the fact that lower heating requires less humidification.

If a large room has to be humidified it is better to use a few small humidifiers - situated in several places in the room - instead of one large one. Only types of humidifiers should be used that work on the principle of evaporation. If water is evaporated without heating just by an airstream passing over a wet surface or through a wet filter a small cooling effect is also achieved. Not recommended are humidifiers that atomize water mechanically by a propeller (aerosol-type) because an accompanying effect is that electrostatic loads are produced. These cause heavy contamination with dirt that is very difficult to remove.

Commercially available humidifiers usually are fitted with a hygrostat, which controls the humidity, switches on the machine and stops it when the desired relative humidity has been achieved. If the hygrostat is mounted at the humidifier it regulates on the basis of the relative humidity nearest the humidifier. Therefore, the relative humidity has to be recorded in other places in the room (where the objects are located) in order to adjust the hygrostat. It should be kept in mind that recording thermohygrometers have to be calibrated at least twice a year with the aid of a psychrometer. Furthermore one should also draw in consideration that the relative humidity in a room may differ locally. At and near cooler areas the humidity is higher: in the case of e.g. 60 % in the centre of the room, in corners or near outside walls it could be considerably higher, and even sufficient for mould growth. The most effective measure against this locally undue moisture is good natural or artificial ventilation (fans). It is well-known that even at rather high relative humidity mould growth can be inhibited or avoided by good ventilation. Leaving a space of 1-2 inches between the back of shelves, cupboards etc. and the (outside) walls promotes air circulation.

If the climatic conditions are not as good as presumed for example in an older building with thick masses of masonry, it might be necessary to equalize drastic changes of relative humidity by technical devices also in the warmer seasons. In addition, there might be an unfavourable climate in certain regions which would require e.g. dehumidification or also humidification in summer. Measures then have to be adapted to the individual case ranging from setting up several humidifiers or dehumidifiers in the rooms, to installing a full air-conditioning system.

Advantages and drawbacks of full air-conditioning

One may raise the questions: is it necessary or desirable to keep rare books and manuscripts in an artificial climate? Is that the best and/or only way to preserve them, in spite of the fact that they have survived up till now for centuries in a non air-conditioned environment? Isn't it exaggerated to demand fully air-conditioned rooms? In answering these questions we must consider the changed environmental conditions to which cultural heritage is exposed nowadays compared to former centuries. Not only air pollution has increased very much, we are used to the comfort of e.g. about 22° C in living rooms and libraries. Moreover we like an excess of light. (Around the middle of the 19th century, 15° C was considered as a normal temperature in heated living rooms.) Due to modern heating technology we are able to maintain higher room temperatures even in not sufficiently heat-isolated buildings with large window areas. So in many cases we do not have favourable preconditions for a more or less equalized natural climate. The climate in modern buildings often follows strong outside climatic changes rather quickly, while in older buildings such changes are dampened and transferred with a delay to the inside. In contrast to the interiors of older buildings with

furnishings made of hygroscopic materials such as natural wood and textiles, the furnishing materials of modern rooms consists of chipboard, plastics and synthetic fibres. Because the latter scarcely absorb water they cannot help equalizing fluctuations of relative humidity. To compensate for all these unfavourable conditions connected with modern life we need machines to maintain a steady neither too dry nor too warm climate. This is not more than an artificial adaptation to the climate under which the objects were made and kept in former times. This is the only chance for the survival of our cultural heritage.

Full air-conditioning, of course, has some important advantages in comparison to setting up just a few humidifiers in the rooms if these become too dry during the heating period. Air-conditioning allows maintaining the room temperature at a moderate level in summer, which is not only pleasant for the visitor but also lengthens the life of manuscripts and books. If it is possible to keep the temperature rather constant (equalizing temperature fluctuations e.g. between day and night or caused by weather changes) and fluctuations in the relative humidity are considerably attenuated, the remaining can be corrected more easily and more completely as in the case of a climate with varying temperatures. Last not least the humidity will be more constant if the temperature does not change (due to the coherence of temperature and relative humidity; see fig. 1). A further important argument for air-conditioning is the possibility of cleaning the air.

There are, however, also several arguments against air-conditioning - mainly the high cost of installation and maintenance. Another point may be - in the case of historic buildings - unavoidable alterations in the building itself. In addition to the installation of the technical air-conditioning equipment the *skin* of the building has to be tightened. That often means replacing of the windows, substituting the frames as well as the panes with a more effective insulating type (Thermopane), installing an air lock at the entrance and possibly also in other places inside the building etc. The suitable construction of a building is a decisive precondition of maintaining a steady climate inside. The building must be as tight as possible (e.g. windows should be locked so that the staff and the visitors cannot open them), air should enter the building only by passing through a filter system. In order to archive this, pressure a little higher than atmospheric pressure has to be maintained inside the building. Last not least it is not cheap to keep an air-condition system running; besides the cost of electricity there are repair expenses, and a well-trained engineering staff is necessary.

If a new building is not to be erected all efforts should be directed to a construction with inherent stability of the climate inside. Not the air-conditioning system should primarily maintain the indoor climate, it only should equalize if drastic changes occur. In the event there is a defect in the air-conditioning plant, no dramatic changes in the climate should take place.

Lighting

Light is energy which can initiate (photo)chemical reactions in a number of materials. Light damage becomes apparent e.g. as fading of colours and inks, also as yellowing and materials becoming brittle such as paper and textiles.

Light consists of a spectrum of rays of varying wave-lengths (which correspond to different colours) in the range between about 400 nm and 760 nm. Beyond this range of visible light there are ultraviolet (below 400 nm) and infrared rays (above 760 nm). The shorter the wave-length the more damaging the rays are, thus invisible UV-radiation is more harmful than visible light, however, the latter can do considerable damage, too (fig. 2). Especially the violet, blue and green sections of the spectrum cause light damage. Thus, removing the UV-rays by filters from the light (which is possible without changing the colour of the light) doesn't protect light-sensitive objects from damage. A colourless UV-filter only reduces the extent of the light damage; just an orange coloured UV-absorbing filter would provide almost complete protection. It is not a question of the technical feasibility to develop a colourless filter for complete protection against light damage. On the basis of physical laws such a filter is principally impossible, because the damaging part of the visible light can only be blocked by a complementary coloured filter. This should be kept in mind if manufacturers of light protecting glass, plastic sheet or lacquers try to convince us that their products can prevent light damage completely. Infrared rays above 760 nm wave-length are not able to initiate or promote chemical reactions as UV-rays and parts of the visible light spectrum do, they, however, produce heat in the various materials. This may cause damage similar to that of elevated temperature, changing temperature or dry inside climate.

Although parchment itself is not very sensitive to light, many colours or illustrated manuscripts as well as some types of inks are damaged by light. In contrast to parchment, paper is rather light-sensitive and so is leather, especially colours on leather. Rare books and illuminated manuscripts belong to the group of highly light-sensitive objects; for these - according to a recommendation of ICOM (International Council of Museums) - the level of illumination should not exceed 50 lx (this illumination is emitted by a 100 watts normal incandescent lamp at a distance of about 1.70 m). Even such low illumination cannot totally prevent light damage, however, it may be considered a compromise for still satisfying lighting. We know that light damage depends on the total amount of light (dose) striking the surface of the objects. The dose is the product of illumination (lx) *and* the exposure time. Consequently we should try to keep exposure time as short as possible.

Considering these factors the following suggestions for lighting can be made:

1. As already mentioned the illumination at the surface of the exhibited objects should not exceed 50 lx. It is not recommended to reduce daylight with blinds etc. to such a low level because this would give the impression of poorly lighted rooms. In the case of low lighting, a dark room in which only the exhibited objects are lighted should be preferred. In a dark or rather dark environment a low-illuminated object already appears bright or at least sufficiently lighted. This impression is caused by the adaptation of the human eye to the dark room - in comparison to this an illumination level of about 50 lx seems bright.

   We can take advantage of this phenomena in another respect: a dark object appears lighter in front of a dark background than before a light coloured or bright background. Furthermore, the colour of the light (colour temperature) influences the sensation of brightness. At the same level of illumination we get the impression of more brightness if the light has more red or yellow (low colour temperature) hue than a bluish one. For low lighting, therefore, incandescent lamps or warm-tone fluorescent lamps should be preferred to cool-tone fluorescent lamps or daylight, which both have a high colour temperature. The disadvantages of incandescent light are a bad colour rendering of blue and green tones and a higher proportion of heat (infrared) radiation. However, measures can be taken against the latter. When installing dark exhibition rooms it should be borne in mind that the visitors eye needs a chance to adapt gradually from bright daylight to darkness. This can be achieved with a suitable layout of the rooms.

2. The exposure of light-sensitive objects to light should be as short as possible even at the low illumination of 50 lx. Very light-sensitive objects such as (illuminated) manuscripts and pages of books should in general be kept in darkness and exposed to light only temporarily. It is quite understandable that the writer or illuminator had no reason to confine himself to light-fast colours, because the pages of a book are usually exposed to light just for the time it takes to read and looking at pictures. Books opened on display were scarcely in the intention of their writers or original owners.

   According to the physico-chemical law which says that the extent of light damage is proportional to the amount of light absorbed by a material we should try to use light as economically as possible. Thus light-sensitive objects at an exhibition should not be illuminated when nobody is looking at them. At least lighting could be switched off before and after opening hours. Additional reduction of exposure time can be attained e.g. if the

visitor himself switches on the light, which then automatically switches off after a while.

Also blinds that open by pushing a button could be used to keep the exhibited objects in darkness. These suggestions are somewhat similar to the curtains on show-cases in older museum furnishings, curtains that were opened and closed by the visitor.

3. The light used for illumination should not contain UV-radiation respectively the UV-radiation must be so low that it can be disregarded. Incandescent light meets this demand, the UV-radiation of fluorescent lamps, however, cannot be ignored (fig. 3). Although there are differences in the portions of UV-radiation in various types of fluorescent lamps, this kind of light is generally more harmful than incandescent light. Thus fluorescent lamps should not be used without an UV-filter. This could be a plastic sheet with an UV-absorber, an UV-absorbing glass (sandwich type with a layer of UV-absorbing material between two panes; special types of acrylic glass which contain an UV-absorber) or an UV-absorbing lacquer. An effective UV-filter should be colourless (a very light yellow hue is also acceptable) and should absorb most of the UV-radiation below 390-400 nm. The effectiveness of a filter can be evaluated on behalf of its spectrographic curve (fig. 4).

   Daylight contains a high proportion of UV and only the shortwave part of it is already blocked by normal window glass (fig. 3). Daylight, however, is, as mentioned above, not suitable for a low level of illumination because of its high colour temperature. Notwithstanding that incandescent light is photochemically less active and thus less harmful than unfiltered fluorescent light it has some drawbacks. About 95 % of the electrical energy put into an incandescent lamp is transformed into heat respectively infrared radiation and only 5 % into light (the light output of low voltage halogen bulbs is slightly better). Fluorescent lamps produce less heat and more light; thus they are more economical than incandescent lamps but their light cannot be directed to a small area. Also the colour rendering of fluorescent lamps is not too good, because of the discontinuity of the spectrum (strong bands which rise above a low continuum, see fig. 3). This drawback can be overcome by using two or three different types which mutually compensate the *gap* in the spectral curves.

   In the case of art objects made of materials such as wood, parchment, paper, leather, ivory, glue etc. the lighting engineer has always to draw into consideration the sensitivity of these materials to heat, dryness and changes of relative humidity. It should be aspired that the temperature of the objects does not rise much more than 1 °C during illumination. A suitable arrangement of the sources of light, special lamps and possibly

the additional use of heat protection filters in front of the light source may help to overcome problems with heat radiation. The installation of the light sources as far from the objects as possible is the first important step. In show-cases, lighting equipment should be external, e.g. a separate unit with good ventilation on top of the show-case. Directed light can also be installed far away from the show-cases, e.g. at the ceiling. Auxiliary equipment for the light sources such as heat producing electric transformers should be placed in such a way that they cannot heat up the interior of the show-case. For beamed (directed) light there are commercially available cool beam lamps with a reflector (mirror) previous to infrared rays, so that a certain portion of heat radiation leaves the lamp at the rear. Up to 85 % of the heat radiation of a spot can be kept off an illuminated object by the use of an effective heat protection filter (e.g. type KG 1, Schott & Gen., Mainz). The effectiveness of infrared- or UV-filters can and should be checked before use or installation by measuring the absorption curve in a spectrometer (fig. 4).

In conclusion I might emphasize that even if all these suggestions are observed light damage cannot be completely prevented. The intention is to reduce such damage as much as possible when light-sensitive objects are shown to the public. It should be kept in mind that light damage is irreversible. If an exposed object is kept in darkness afterwards, it will not regenerate. If the object is exhibited and illuminated again, new light damage can occur, which will increase previous light damage.

Air pollution

There are two sources of pollutants, which may have a damaging effect on manuscripts and rare books. One is the air outside, another can be unsuitable materials used for furnishing the room or in the construction of show-cases.

With respect to manuscripts and books damage is to be expected if nitrogen oxides, ozone, sulphur oxides, hydrogen chloride and hydrogen fluoride are present. All these compounds are airborne. Due to their strong oxidizing power nitrogen oxides and ozone attack all organic materials such as parchment, leather, paper as well as dyestuffs, inks, media etc. and also some inorganic pigments. As it has been known for rather a long time sulphur oxides, converted in situ to sulphuric acid, are seriously damaging to paper and leather. Hydrogen chloride and fluoride show effects like other acids, however, they are not present in higher concentration all around. These compounds are emissions from certain industries and thus mainly restricted to specific regions. A serious damaging factor is also dust (dirt), especially if it is very fine. Heavy metal oxides, always present in dust catalyse the oxidation of the less aggressive sulphur dioxide to sulphur trioxide, respectively the strongly corrosive sulphuric acid. Dust absorbs

damaging pollutants and in forming a sort of compress on the surface of the objects it intensifies the attack of the pollutants. Last not least very fine dust behaves like a dyestuff; it often cannot be satisfactorily removed with usual cleaning procedures.

Similar to light damage, alterations caused by air pollution are irreversible. In contrast to living organism dead material cannot regenerate. All single events of damage cumulate - this may underline the need for clean air in exhibition rooms and storage rooms.

There are two possibilities to preserve objects from the attack of air pollution: A fully air-conditioned room or building in which the air drawn from the outside is carefully filtered. The other possibility is to keep the objects in tight show-cases with an opening (hole) fitted with an active carbon filter. In the case of an air-conditioning system the air from the outside has to pass at least two filters which remove one after another the coarse particles, the fine and ultrafine particles as well as gaseous pollutants. For the choice of an effective filter system it is necessary to know the type and the concentration of pollutants as well as the contact time of air and filter (velocity of the air stream). Filters with high efficiency have a high resistance to the air stream, using them requires much energy. Filters, however, which absorb just the coarser particles are nearly useless, because coarse dust particles have a low catalytic effect and can be removed from surfaces quite satisfactorily. The commonly used effective filter material for air pollutants is active carbon. Somewhat less effective are washers in which the air passes a shower (and is simultaneously humidified). Not used should be filters with a tacky oil surface and electrostatic dust filters. The former load the air with small amounts of oil aerosols, the latter produce small quantities of ozone. A filter system can only be efficient in an air-conditioned building, in which a little overpressure is maintained. Usually about 1/5 of the whole air in an air-conditioned building is fresh air, that is filtered air drawn from the outside; the other portion, circulated in the system, should also pass filters although it might not be absolutely necessary. The advantage would be the elimination of pollutants produced inside.

The variety of pollutants which can occur inside from natural and synthetic materials is greater than those of airborne contamination outside. Just to name a few examples: Newly constructed buildings or rooms should stand at least one year before they house exhibition objects. During that time the rooms must be well ventilated. Fresh lime mortar and concrete emit alkaline aerosols during some time. Apart from this, it takes about one year to get the air-conditioning plant working in such a way that a specific climate can be maintained without fluctuations. This might not primarily depend on the air-conditioning system itself but on disturbing effects produced by drying and setting mortar. Furthermore painted and lacquered surfaces, adhesives etc. should have lost their volatile components before the objects are put into rooms or show-cases. Chipboard

is certainly not a suitable material for furnishing rooms in museums, libraries and store rooms. Apart from the fact that chipboard does not behave like natural wood as a humidity buffer the cement which binds the chips emits formaldehyde as a decomposition product. This can be harmful in itself, however, formaldehyde easily oxidizes to formic acid which is a highly corrosive agent. Plastic material probably cannot totally be avoided, however, a warning is necessary in the case of PVC (e.g. floors). In the event of a fire hydrogen chloride developing in the course of the decomposition of this plastic material may lead to disastrous damage on the building as well as on the objects. Some kinds of natural wood like oak and several exotic species emit acidic vapours, which cause corrosion on metals. Especially sensitive to organic acids is lead, however, brass and other copper alloys as well as iron and steel are attacked, too. There are a lot of other possible sources of pollutants such as sealing materials, paint and varnishes, chemicals used for the treatment of textiles etc. which might be difficult to exclude from modern furnishing. In this respect, there are only few absolutely safe construction and furnishing materials such as metals, glass, some types of wood, so called acid-free paper, textiles without a chemical finish. Fortunately not all vapours emitted from various construction or furnishing materials are harmful to every object; the material of the object must be specially sensitive to a specific chemical compound. In some cases it might be advisable to test the material, which is intended e.g. for the construction of show-cases or furnishing purposes. In such test, the material in question and the materials of which the object is made, are placed in a closed vessel at high humidity and elevated temperature for some time. These conditions accelerate decomposition reactions in the construction or furnishing material as well as the attack of the decomposition products on the object's materials (accelerate artificial aging).* Focusing - after this review of possible damaging materials - on manuscripts and rare books in libraries I cannot see too many damaging factors produced inside. There is one exception: materials which release formaldehyde (certain types of chipboard and adhesives), which may act as a tanning agent for parchment and animal glue. Apart from this formaldehyde has recently been detected as unambiguously carcinogenic.

A practical and effective measure to forestall damage by inside produced pollutants is good ventilation. This concerns also the air exchange between the show-cases and the room. On one hand a well-tightened show-case may have the advantage of equalizing climate changes, of reducing the attack of dirt and gaseous pollutants. On the other hand damaging compounds possibly released by the construction and furnishing materials accumulate in a tight show-case so that

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*W.A. ODDY: The Corrosion on Metals on Display, *Conservation in Archaeology and the Applied Arts*, IIC, London, 1975.

an attack on the object can occur. Therefore, a good solution seems to me the already mentioned type of show-cases which is well-tightened but also has an opening fitted with an active carbon filter (*controlled air exchange*).

If, however, a constant microclimate should be maintained in a show-case which is in a room with fluctuating relative humidity such a construction is not suitable.

I might conclude with a few remarks on the construction of a room in the Herzog-August-Library, Wolfenbüttel, in which treasures of the library will be shown to the public. Considered is a room that offers the security of a safe-deposit room with windows directed to the adjacent visitors' room. The objects are exhibited behind thick safety glass in the "treasure room", which can be considered as a kind of walk-in show-case. The visitors' room should be kept as dark as possible (of course also the treasure room), so that the objects appear well-lighted even at a level of 50 lx. In addition all measures will be taken to keep the exposure time as short as possible, including the intention to exchange the exhibited objects from time to time. An air-conditioning plant will maintain constant temperature and relative humidity as well as care for clean air. The amount of air pollutants such as sulphuric oxides and nitrogen oxides is rather high in Wolfenbüttel - it has about the same level as in bigger towns or industrial areas. Therefore, great significance has to be attached to the filter system. Careful choice of materials for furnishing purposes should help to avoid indoor produced air pollution.

Reference

A comprehensive view (including 260 references) on climate, lighting and air pollution is given by G. THOMSON in his book *The Museum Environment*, London, Boston, Butterworths, 1978.

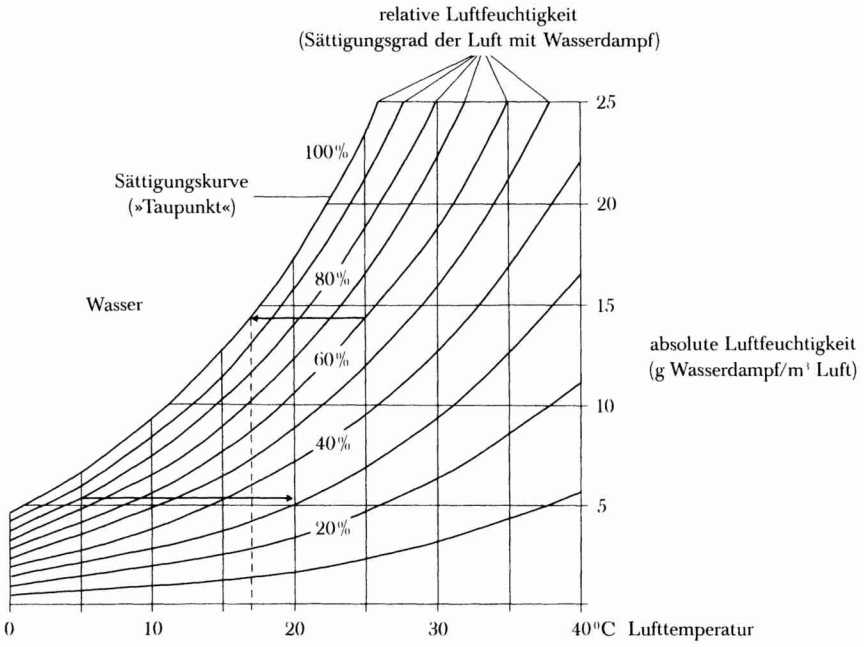
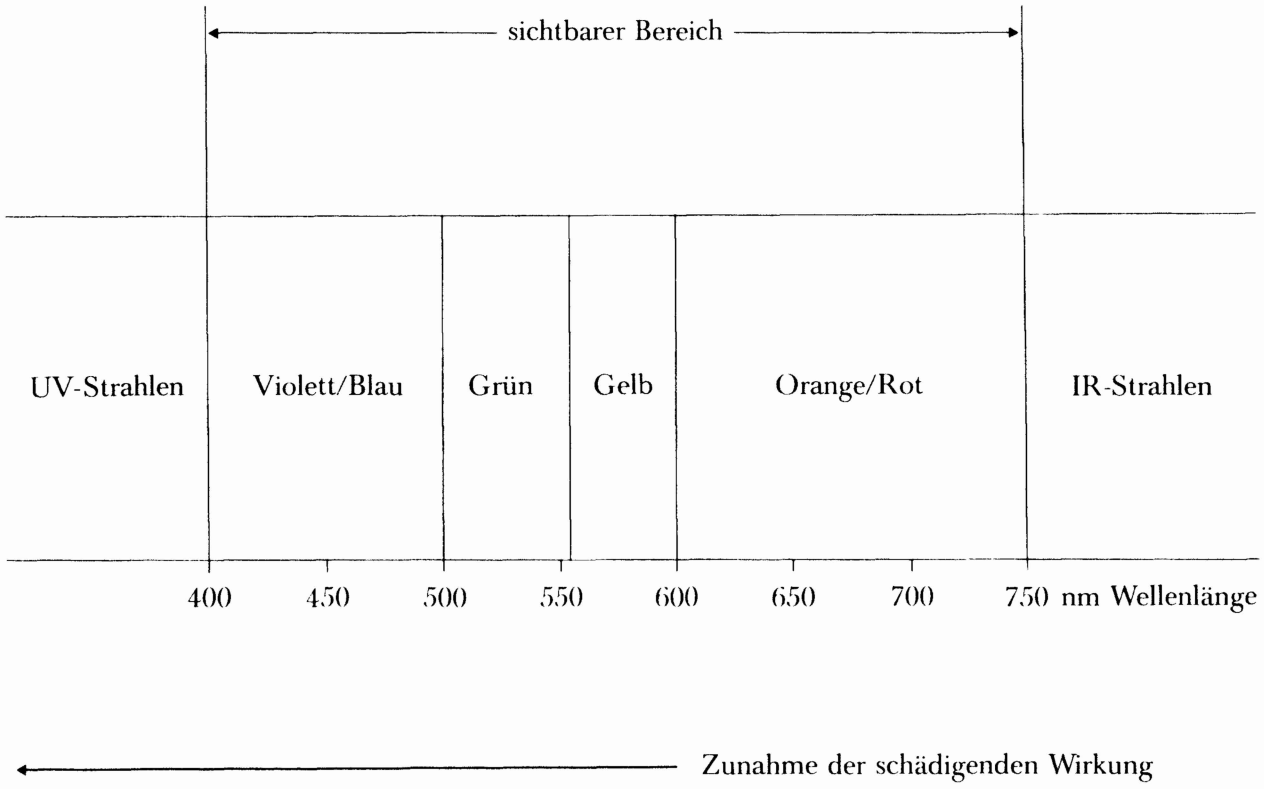


Fig. 1. Coherence of relative humidity and temperature

Parallel to the temperature axis the decrease or increase of relative humidity (at constant absolute humidity) can be read. The lower arrow e.g. shows that if air of 5° C/80 % relative humidity is heated to room temperature (20° C) the relative humidity decreases to about 30 % (explains dry climate in heated rooms during winter). The upper arrow: if air of 25° C/60 % RH is cooled to 17° C condensation will occur (precipitation of water on cooler walls, windows etc.)

If a constant relative humidity is wanted at varying temperature, water (vapour) must be added or withdrawn.

Adding or removing water changes the absolute humidity. Hygroscopic materials respond to changes in absolute humidity if the relative humidity remains constant.



1 nm (Nanometer) = 1 Millionstel mm

Fig. 2. Coherence of wavelength of light and damaging effect

The photochemical activity of light and UV-rays increases with decreasing wavelength (because the energy of radiation increases in this way).

The orange and red range of the spectrum is not able to initiate photochemical reactions as well as infrared rays. These, however, heat up the illuminated objects. The photochemical active radiation of the visible light could be removed only by an orange coloured filter.

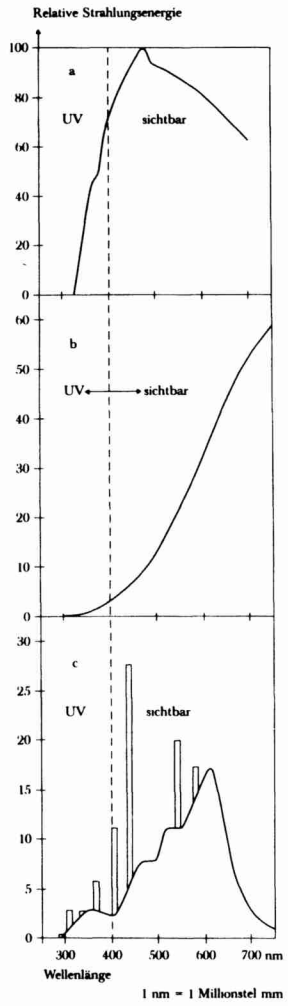
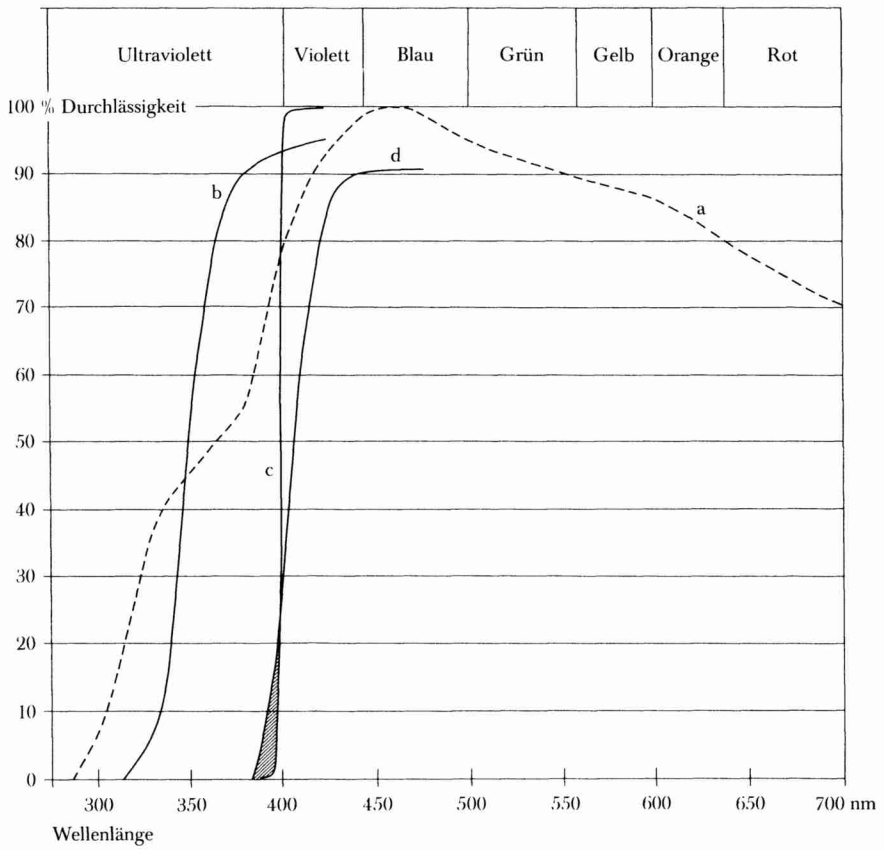


Fig. 3. Curves of spectral energy distribution of various light sources

a) daylight, overcast sky, filtered by common window glass (colour temperature 6400 K). The maximum in the blue range indicates high photochemical activity.

b) incandescent light (colour temperature 2800 K) causes less photochemical damage than daylight, because its main energy belongs to the yellow, red and infrared section of the spectrum (heat production).

c) light of a "cool-white" fluorescent lamp (colour temperature 4300 K). Strong bands rise above a low continuum; this discontinuity of the spectrum impairs colour rendering. More or less strong bands in the UV-range as well as in the blue range cause photochemical damage. In contrast to incandescent light, the light of fluorescent lamps shows low energy in the red and infrared range (less heat).



1 nm = 1 Millionstel mm

Fig. 4. Judging UV-absorbing filters on the basis of spectral transmission curves

a) sun light
b) common window glass absorbs only the short-wave UV-radiation of the daylight
c) ideal would be a filter with an absorption curve following the line c
d) a UV-protection filter (glass, sheet, lacquer) improves as its absorption curve approaches to c or as smaller the hatched area is. Shifting the curve to the right increases the light protection, however, at the same time a yellow hue appears.