HERITAGE COLLECTIONS COUNCIL

GUIDELINES FOR ENVIRONMENTAL CONTROL

IN CULTURAL INSTITUTIONS

Consortium for Heritage Collections
and their Environment

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CONTENTS **Page**

TABLES AND FIGURES

GUIDELINES FOR ENVIRONMENTAL CONTROL OF CULTURAL INSTITUTIONS

1. INTRODUCTION

The conservation of objects relies, above all, on the environment in which they are stored and displayed. In the conventional wisdom of museum climatology, optimal environments for the preservation of materials and artefacts are specified as very narrow ranges of conditions, especially for temperature and relative humidity.

Because such narrow ranges of conditions are quite difficult to maintain, far too often it is assumed that an artificial environment is required. The higher status the institution, the more likely that to achieve such environments, it is thought necessary to provide mechanical means of ventilation with artificial heating and cooling, and to rely on artificial lighting. To assure reliability and relative efficiency, high standards of mechanical services need to be coupled with similarly high standards of building fabric integrity. Most museums, therefore strive towards the installation of an (HVAC) Heating, Ventilation and Air-conditioning system, and that decision, in turn, influences how they deal with the building in which it is to be installed.

However, problems inherent in this approach have been apparent for some time. As Colin Pearson, referring to experiences with institutions in South East Asia and the Pacific, has stressed:

> 'Air-conditioning is very expensive to install and maintain, and unless high quality (and therefore price) systems are used, air-conditioning can often cause more damage than no air-conditioning. There is unfortunately a neurosis that without air-conditioning, museum, gallery, library and archive collections will rapidly deteriorate. This is not the case. It is more important to have a stable environment than specific levels of temperature and relative humidity, and this can be achieved by careful building design'.

This is especially true of small museums, historic houses and other heritage buildings where air-conditioning is not always a practical option. At its worst, installing air-conditioning in previously unconditioned buildings can have disastrous results. For instance, where humidity is not adequately controlled, with resultant severe problems of condensation and moisture movement through walls. Similarly, if a new building is designed to depend completely on its mechanical systems for environmental control, the risk of unacceptable conditions when those systems fail or even if they are only turned off to save energy is often unacceptably high. The prohibitive initial costs of installation, the high maintenance and running costs, and in the case of heritage buildings the necessary removal of some of the historically important fabric, mean that alternatives must be found.

Achieving appropriate environmental conditions in museums and other repository buildings is a specialised architectural task, which is often not well understood by either the heritage conservation or architecture professions. As the large majority of the world's museums do not have full air-conditioning systems, there is an obvious need to concentrate on their needs with respect to climate control.

The following *Guidelines* emphasise the analysis of local climate conditions and appropriate building strategies, which might minimise the reliance on full air-conditioning. Even where air-conditioning might be employed, minimising external loads, and appropriate operation of the building in response to the local climate, may have significant benefits in reducing energy costs, and the incidence of catastrophic failure of the environmental control systems.

2. ENVIRONMENTAL REQUIREMENTS FOR COLLECTIONS

When deciding on the environmental requirements for the long term preservation of cultural collections, those housed in museums, galleries, libraries, archives, historic houses, cultural centres and keeping places, and in private homes, it is necessary to consider a number of parameters which include:

- type, significance, use and condition of the collection;
- type of building housing the collection, and the role the building plays in providing a stable environment plus keeping out pests and pollutants;
- regional and local climatic data including seasonal and daily fluctuations;
- technical feasibility to implement and maintain a specific environment within the building and taking account of the local climate; and
- ability to fund capital costs, and operating, and maintenance costs.

The next step should consist of a comprehensive risk assessment of the collection and the building in which it is housed (section 5). Often, natural and other disasters, frequent and improper handling, pests, and inadequate security and fire protection pose a greater risk to collections than fluctuations in environmental parameters. Available resources should therefore first be invested in the mitigation of the greatest risks.

Once it is determined that environmental settings and fluctuations are the largest remaining threat to the long-term survival of a collection, a plan for environmental improvements can be drawn up. For this purpose it is essential to know the nature and condition of the collection and to fully understand the performance characteristics of the building within the local climate. Any environmental improvements should start with decisions about the safety and integrity of the building envelope and, where applicable, the extent to which they are allowable within the historical/aesthetical context. Only after this task has been accomplished can one sensibly plan ways to further improve the interior environment.

Before deciding on the levels of relative humidity and temperature, permissible fluctuations and seasonal drifts, as well as control mechanisms for air pollutants and light levels, one has to understand if the deterioration of the collection is mostly chemical or mechanical. One should also know what percentages of the collection are of very high, high, medium, or low vulnerability to environmental damage. This can be provided by the risk assessment survey (section 5).

Based on this knowledge of the collections, the building, and the local climate one can approach a decision about the proper environmental control systems and settings. Different standards may be required for different types of collections. The use of microclimates should be considered as a valid strategy for protection of the more vulnerable parts of the collection.

2.1. Methodology

1. Determine local climatic conditions. These will vary according to regional climates tropical, sub-tropical, temperate and inland etc. The regional climate will then be modified by local geographical features and landscapes, proximity to water, industry and transport systems. Use climate data from the Department of Meteorology, noting that it may need to be interpreted for such local factors.

2. Use the information to determine basic temperature and relative humidity set points, and whether seasonal drifts are appropriately considered, and their magnitude.

3. Also determine if problems may arise, due to local levels of air pollution and the potential for infestation by pests, including insects, rodents, birds etc.

4. Carry out a risk analysis of the collections to determine if, and how many of the objects in the collections will be affected, or the effect this might have on securing loans of material from other collections if standards for environmental control are relaxed.

5. Carry out an environmental survey of the internal climate of existing buildings and compare with external values. This would include temperature, relative humidity, air movement and direction, rainfall, daily angle and duration of the sun, illumination and Ultraviolet levels, levels of air pollutants, signs of pests etc.

6. Then, depending on the level of availability of funds to install and maintain facilities and equipment, determine the level and type of building, facilities and equipment required to provide a safe and stable environment for the collections. This would include the building location and surrounding features (landscapes, car parks etc.) design, orientation, structure, materials of construction, interior fittings and fixtures, and involve control of temperature, relative humidity, pollutants, light levels and pests etc.

7. Following construction, check on the performance of the building as designed or retrofitted to ensure design criteria are met, there are no faults, and the building functions according to specifications.

8. Finally, carry out an energy audit of the proposed facilities, to determine whether they are the most cost effective in the long term.

9. Regularly monitor the collection and the costs of providing the required environmental conditions to ensure that the building, facilities and equipment are operating to optimum specifications, and that cost savings are as predicted. Make any necessary modifications and repeat the monitoring.

3. CONSERVATION PROBLEMS FACING CULTURAL COLLECTIONS

It is generally accepted that the factors causing the most damage to cultural collections are temperature (T), relative humidity (RH), light levels, (specifically illumination and UV radiation), air pollution (gases and particulates such as dust and soot), and pests (including insects, rodents and birds) and probably most important, people. The latter includes mismanagement, mishandling and carelessness. It is important to control, or at least reduce, the affects of these agents in order to ensure the long-term preservation of cultural collections. Before discussing the recommended environments for cultural collections in different climatic zones, it is first necessary to understand what damage can be caused to such collections by these agents of deterioration.

3.1. Temperature

Temperature alone can cause damage to collections. An increase in temperature will cause an increase in chemical reaction rates, the general rule being that there will be a doubling of reaction rates for every 10ºC rise in temperature. Materials particularly prone to damage by high temperatures are those which tend to self destruct such as acidic paper, acetate and nitrate films, celluloid and rubber, also objects which contain waxes or resins such as ethnographic collections and wax/resin lined paintings.

The variation of temperature, between night-time minimum and day-time maximum, are generally small in hot humid environments, but can be large in hot dry and temperate climates. These 'diurnal' fluctuations are more damaging than relatively large seasonal changes in temperature, where there is plenty of time for materials to adjust to the changed conditions. High diurnal changes can cause damage to objects with restrained layers, such as enamels, and possibly wooden veneers and inlays, through expansion and contraction.

The other and probably most significant influence of temperature is its relationship with relative humidity. In an enclosed space such as a museum, display room or display case where there is not much air exchange, an increase in temperature will cause a decrease in relative humidity, and vice versa. Therefore, high fluctuating temperatures will induce high fluctuating relative humidities, but in the opposite direction, and as will be discussed in the following section, such changes in RH are in most cases much more damaging than changes in temperature.

3.2. Relative humidity

Relative humidity (given in percentages) is defined as the amount of water vapour present in a given volume of air, divided by the maximum amount of water which the air can hold at that temperature. As with temperature, a high Relative Humidity (RH) increases deterioration rates of most materials by providing more water to take part in chemical reactions.

The main problems caused by relative humidity are that if too high, above an RH of about 70 per cent, there is the probability of fungal growth, and also the corrosion of metals and crizzling of glass objects. If too low, below approximately 40 per cent, desiccation of organic materials will occur.

This is accentuated further by high and rapid fluctuations in RH. However, it has been found that few materials will respond significantly to fluctuations of less than one hour duration. Therefore, the fluctuations which characterise the controlled cycling of air conditioners (especially the 'wall type') for example, are normally unimportant. Due to the main fluctuations of RH being experienced on a diurnal basis, allowable per cent RH fluctuations are normally specified on a daily basis, and sometimes in addition, as an allowable seasonal variation on an annual basis.

The extreme level of high RH occurs with precipitation rain, which can be high in some climatic zones and at certain times of the year. It is necessary to protect against rain entering a building, remembering that rain can often be blown horizontally by strong winds. If rain falls relatively evenly over the year, then there should not be too many problems. However, in 'wet seasons' when 80 per cent of the annual precipitation may fall in a few months, and on a daily basis is followed by hot sunshine which evaporates the rain, extreme daily cycles of relative humidity may be experienced.

When there are extreme fluctuations of RH, this creates a dangerous situation. In response, moisture will move in and out of organic materials, causing them to expand and contract in a cyclic fashion. In time, this will cause the material to disintegrate. Fluctuations in internal RH levels can be caused by an external fluctuating temperature on a building, direct sunlight being able to enter a building and falling on an object or display case, the turning on and off of incandescent spot lights, or an air-conditioning system being turned on during the day and off at night etc.

There are about 100,000 species of fungi, of which a relative few, the surface fungi including *Aspergillus Niger*, *Cladisporium*, *Penicillium* and *Stachybotrys*, are of concern to the conservator. They grow on and in organic materials, and this is known as mould, which can produce brightly coloured surfaces. The growing or food-getting part of a fungus is made up of long, hollow, branched cells called hyphae, which as an aggregate are called mycelium or the fungal colony. They reproduce by the means of spores, which falling on a moist substrate will germinate within hours under the right conditions. Because the spores are so light they can travel over long distances, even with only minor air movement.

As fungal spores are always present in the atmosphere, they just require a sustained high RH for a certain period of time depending to some extent on the fungal species for the spores to propagate. The higher the RH the shorter the time. For continuing viability, fungi require water, oxygen, heat and food. The most important of these is water, as fungal tissue itself consists of about 95 per cent water. Fungi become more tolerant to different moisture conditions the better the source of nutrient. Organic materials such as paper, textiles, leather, especially if containing waxes, fats or oils, are ideal nutrients for fungal growth. Fungi can also grow on the surfaces of inorganic materials such as metal, glass and ceramics if water has condensed there, and especially if dirt and dust are present to provide nutrients. Fungi are very temperature tolerant, being active between 0 60°C, the optimum being 15 20°C. Many different species can be found inside any building.

As mentioned earlier, fungi require an RH of above approximately 70 per cent to germinate and grow. However, it is necessary here to consider not just the RH of the air surrounding an object but also the moisture condition of the surface of the object. If the object has a high moisture content then even though the RH of the surrounding air may be relatively low, there may be sufficient moisture present on the surface for mould to grow. On the other hand, even in a high RH if there is sufficient air movement at the surface of an object, this may be sufficient to reduce the surface moisture content to below the mould formation level (section 7.2.2.). Surface moisture conditions are more important than the RH of the surrounding air.

3.3. Light

Light is more damaging to cultural collections than temperature. Light consists of bundles of energy called photons, which travel in a wave motion and this is known as electromagnetic radiation. The shorter the wavelength and higher the frequency of vibration, the more energetic the radiation. When these vibrating photons collide with a substance they react with the surface layers and cause photochemical damage such as fading of dyes, yellowing of paper, darkening of varnishes, embrittlement of textile fibres etc.

Natural daylight consists of visible light over the frequency range of 380-760 nm, plus UV radiation at shorter wavelengths, and (IR) radiation at longer wavelengths. The most damaging part of the spectrum is UV radiation. In addition, it does not contribute to our being able to see an object on display. Infra radiation produces heat, and as discussed earlier, this can damage materials. Therefore, if direct sunlight falls on a museum object it is bombarded with damaging photons from the UV radiation, and is also heated, which causes a lowering of relative humidity of the surrounding air. When the sunlight moves away although there are less damaging photons, the temperature drops and the relative humidity increases. The total effect of these cyclic changes can be devastating, especially to organic materials.

Although not as damaging as sunlight, artificial daylight can also damage cultural objects. Incandescent lamps such as spot lights, produce IR radiation (heat), but a relatively low level of UV radiation. On the other hand, fluorescent lamps although cool in temperature, usually have a high UV output. Neither system is ideal, and the control of light levels will be discussed in sections 4.2 and 7.1.2.6.

3.4. Air pollution

Outside air pollution consists of various gases and particulate matter from industrial processes, motor vehicles and agricultural practices. In addition many Australian cultural institutions are located in towns or cities close to the sea, with resultant salt contamination.

The typical outdoor pollutants of ozone, nitrogen dioxide, sulphur dioxide, hydrogen sulphide, and sulphuric and nitric acid vapours are brought into the museum building.

Without air-conditioning, the indoor levels are similar to those outdoor, although the levels of ozone and nitric acid are reduced as they are scavenged by interaction with interior surfaces. Indoor levels of ozone can be as high as 70 per cent of the outdoor where there is high air exchange rates such as the use of natural or forced ventilation. It can drop to as low as 10 - 20 per cent in poorly ventilated buildings. Similarly, the levels of air-borne particulates can be as high indoor as outdoor with good ventilation, unless air filtration is used. Therefore in general, many museums can expect to have as much air pollution inside as outside unless air filtration systems are used.

In addition to the presence of outdoor pollutants, the materials used for construction of museum furniture, in particular storage and display cases, can also produce pollutants. These include different woods, plastics, paints, adhesives, textiles, rubber gaskets etc. The type and concentration of pollutant depends on the materials used, but carbonyl pollutants, such as formic and acetic acids and formaldehyde, which can be released by these materials, are particularly damaging to cultural collections (see also section 10).

The effects of air pollution are well known. Sulphur oxides and nitrogen oxides form acids when combined with high relative humidity and these can react with building materials to form salts which slowly dissolve. One advantage of high rainfall is that air pollutants can be washed away from building materials. Acid gases react with objects in the museum causing red rot in leather, accelerated acid degradation of paper and other organic materials, and the corrosion of metals. Ozone also reacts with organic materials causing colour changes and fading of dyes, and with sulphur containing compounds such as rubber, causing it to become hard and brittle. Organic acid vapours cause corrosion of metals, in particular lead alloys, and tarnishing of silver and copper. Particulates are unsightly, they can harbour moisture and other pollutants setting up corrosion cells on metals, and may scratch when being removed. Ideally, all pollutants should be removed from a museum environment, but this may be difficult when natural or forced ventilation is required to control the problems of high relative humidities (see section 7.1.2.4.).

3.5. Insects and other pests

There are numerous pests which can attack and damage cultural collections. There is a wide range of insect species in Australia, most of which have been found in cultural institutions, and the problems depend to some extent not only upon the climate but also on the type and availability of materials. They will eat most organic materials in collections, and some species can also destroy the wooden cabinets and even buildings housing the collections. Other pests such as rodents, birds and bats have also caused damage to collections. They eat, chew and soil collections and are also a potential health hazard.

When dealing with pests, and the most common are insects, it is important to know and understand their life cycles, eating habits and susceptible materials. Ideally, any insect found in a collection should be identified to determine whether it is a threat.

This can be done through the various publications which include pictures of insects, or by contacting the Entomology Department at the local State Museum, the State Department of Health, or CSIRO Division of Entomology in Canberra.

Factors such as temperature, relative humidity, atmosphere, light, shelter and sources of nutrition, all affect the rate of development and breeding of insects. Understanding these factors can provide guidelines as to methods which can be used to control insect problems

1. Temperature

Insects are active between 5 - 45°C, and eating and reproduction are optimal at about 30°C. Above 40°C insects become distressed, and above 55°C, most insects will die within an hour.

Low temperatures result in low insect activity and therefore cold storage is a preservation option. Freezing to -20°C will kill all stages of insects (egg, larva, pupa and adult). Freezing and heating are methods which are currently being used for insect pest control in small museums.

2. Relative Humidity

An RH of about 70 per cent is optimal for most insect species. A low RH retards breeding, therefore most insects gravitate towards high RH areas such as leaking taps and pipes, areas of condensation or rising/falling damp. The two notable exceptions are clothes moths and carpet beetles which favour a dry environment.

3. Atmosphere

An increase in carbon dioxide and/or decrease in oxygen results in a decrease in feeding. If high enough and for long enough, an atmosphere of carbon dioxide will kill all stages (egg, larvae, pupa, adult) of insects. Low oxygen (anoxic) environments are being promoted for insect control in museum collections.

4. Light

Light and darkness and the various levels of light constitute a series of niches each filled by particular insect species. Clothes moths and cockroaches, for example, are purely dark-loving insects. The length of day/night (light/dark) can affect behavioural changes such as breeding and hibernation. UV light (e.g. from mercury vapour lamps) is strongly attractive to nocturnal insects, and therefore should not be used for external lighting close to a museum building (section 7.2.3.3.).

5. Shelter

The availability and quality of shelter is critical for some insects. Cockroaches, for example, are thigmotactic (they need contact with upper and lower surfaces of their bodies), and seek out appropriate refuge in cracks and crevices. Good building maintenance can reduce this problem.

6. Nutrition

The growth rate and adult size of insects depends on the availability and quality of nutrition. Furniture beetles can take 1-3 years and powder post beetles 4-12 months to develop. High nutrition value foods generally result in fast growth rates, and insects often attack a food stained area on a textile first. The moisture content of the food source is also important, and wood borers require moisture contents of over 10 per cent. If levels drop, size and growth rates of the insects are affected.

4. RECOMMENDED LEVELS OF ENVIRONMENTAL CONTROL

4.1. Temperature and Relative Humidity

Temperature (T) and RH are interrelated in that for an enclosed space such as a building, store or display case, an increase in T will produce a decrease in RH, and vice versa. High levels of T will cause materials to deteriorate faster. Levels of RH above about 70 per cent will promote the growth of mould on organic materials and cause metals to corrode, and below 40 per cent organic materials will dry out. Rapid fluctuations in T and RH will cause the most damage.

For years the generally accepted levels of temperature and relative humidity required to preserve cultural collections in museums were 20±2°C and 50±3 per cent RH respectively on a daily basis. However, it is often forgotten that these levels are not recommended for museum collections in countries with hot humid climates. In fact 65 per cent RH with air circulation, is recommended for mixed collections in the humid tropics.

It has been found that for organic materials which have naturally acclimatised to a mid-range relative humidity of around 50 per cent, a variation in RH on a daily basis of:

- 10 per cent (e.g. 40-60 per cent RH) represents a low risk to most organic materials.
- 20 per cent is dangerous to some composite objects.
- 40 per cent is destructive to most organic objects.

To translate this to tropical climates where the normal acclimatisation point would be 65 per cent RH is more difficult, as above 70 per cent RH objects may be affected by mould growth if exposed for a period of time. However, the figures do give some indication of the ranges of RH within which objects can expect to survive reasonably well.

It is therefore recommended that levels of T and RH should if possible be kept within the boundaries given below. If this is not possible then it is necessary to reduce (a) high or low levels, and (b) fluctuations in T and RH.

For *hot humid* climates:
Temperature 22 - 28°C, Relative Humidity 55 - 70 per cent on a daily basis

For *hot dry* climates:
Temperature 22 - 28°C, Relative Humidity 40 - 60 per cent on a daily basis

For *temperate* climates
Temperature 18 - 24°C, Relative Humidity 45 - 65 per cent on a daily basis

Although these levels can be achieved using air-conditioning, serious consideration should be given to the use of passive climate control. This approach looks at the building envelope and materials of construction of the building and fittings. Then through an understanding of the external environment and the internal requirements to provide a stable and safe environment for the objects, measures can be taken to improve the situation. This may involve natural and forced ventilation, insulation, shading, and consideration of the surrounding landscape etc (discussed in section 7).

4.2. Light

The recommended levels of illumination and UV have in general been accepted by the museum profession, and there are standards for museum collections determined by the vulnerability of different materials to light exposure. The aim is to reduce the most damaging part of light, the UV radiation, as much as possible, and to keep the illumination to a level at which it is possible to view the object, noting again that fugitive dyes and delicate organic materials cannot tolerate as high levels of illumination as inorganic materials such as metals, glass and ceramics. The generally accepted levels are given in Table 4.1.

Table 4.1. Recommended levels of illumination and UV

Material	Illumination lux (lumen/m^2)	UV (µwatt/lumen)	(µwatt/m^2)
Very Sensitive: Includes textiles, water colours, prints and drawings, manuscripts, ethnographic objects	<50	<30	<1500
Sensitive: Oil and tempera paintings, undyed leather, horn, oriental lacquer	<200	<75	<15,000
Insensitive: Metal, stone, ceramics and glass, jewellery	<300	<200	<60,000

The maximum levels of illumination assume that the museum or cultural centre is open for seven hours per day, and for 362 days per year (closed only three days per year). Many small museums will be open fewer days and shorter hours, and the rest of the time the collections should be in the dark.

It is necessary to multiply the lux levels by the number of hours of exposure to determine the total lux.hours on an annual basis. Typical exposure values for the different types of materials are given below:

Very Sensitive materials at a maximum level of 50 lux:

Total lux.hours is 362 days x 7 hours x 50 lux = 126700

Sensitive materials at a maximum level of 200 lux:

Total lux.hours is 362x7x200 = 506800

It is recommended that the lux.hours for Very Sensitive materials should not exceed 200000 (200 kilolux.hours). For Sensitive materials such as wood and leather the recommended levels are 650 kilolux.hours. For other materials not sensitive to light, keep out of direct sun and avoid high-powered incandescent spotlights.

Comparison with these recommended levels will indicate whether the objects are receiving too much illumination on an annual basis, and also provide guidelines as to the amount of reduction in illumination necessary to preserve the collections. The easiest way of doing this is by using the reciprocity principle, e.g. approximately the same amount of damage will be caused by exposure for 5h at 100 lux as for 10h at 50 lux (both receive 500 lux.hours of illumination). This means that if the illumination on say a sensitive textile is 100 lux (twice the recommended level over one year see Table 4.1), then it can safely be displayed for six months, the lux.hour factor being the same. The rest of the year the textile must be stored in the dark.

Ideally the levels of UV should be zero, or at least below the figures given in Table 4.1. It is important when measuring UV, that the illumination levels (in lux = lumen/m^2) are also measured, which when multiplied by the UV reading in µwatt/lumen will give the total UV energy falling on the object in µwatt/m^2.

The above levels of illumination and UV, although recommended world-wide, are more applicable to institutions in temperate climate zones. In tropical zones the solar radiation is strong, and as being overhead is more direct with higher UV (often double) and illumination levels than for temperate climates. This means that control is more important, but often more difficult, as museum buildings in the tropics are usually quite small and rely on an open structure to allow air flow through the building.

The compromise for small museums in tropical climates, is for organic materials, avoid illumination levels above 1000 lux, e.g. from bright artificial light and daylight at open doors and windows, and control the UV to less than 75 µwatt/lumen (ie. a maximum UV of 75,000 µwatt/m^2). There must be absolutely no direct sunlight falling on an object. The following levels of illumination and UV are therefore recommended for small cultural institutions:

Illumination:

Very Sensitive and Sensitive artefacts:
preferably < 200 lux, but definitely <1,000 lux

Insensitive artefacts:
unlimited, but subject to display requirements

UV Levels:

Very Sensitive and Sensitive artefacts:
<75 μ watt/lumen (15,000-75,000 μwatt/m^2)

Insensitive artefacts:
Not applicable, but keep as low as possible

It is also recommended that in addition to the above, consideration be given to the monitoring and control of the maximum lux.hours exposure time in each type of functional space.

4.3. Air pollution

Although several organisations have made recommendations for acceptable levels of air pollutants in museums, these can only be achieved with air cleaning equipment. It is necessary, through the risk assessment process, to determine the potential sources of pollutants and try and avoid them. This can be difficult in hot humid climates where good ventilation using outside air, may be used to reduce the problems created by high levels of relative humidity.

Indoor air pollutants arising from materials of construction of display cases and storage units can be as damaging as outdoor pollutants. However, it should be possible to reduce these by careful selection of building materials (see sections 9 and 10)

4.4. Insects and other pests

There are no particular standards for the allowable number of pests which can be tolerated in a museum. This will depend on the type of pest and the damage they cause. Ideally, there should be no pests present, and all pests insects, rodents, birds and bats etc. should be prevented from entering the museum in the first place. It will be necessary to implement an Integrated Pest Management approach to pest control (discussed in section 7.2.3.1.).

5. RISK ASSESSMENT OF COLLECTIONS

In order to plan and provide the best form of environmental control for cultural collections, it is important to determine the most important agents which can cause damage to the collections. As discussed in section 3, there is a range of agents including incorrect and fluctuating T and RH, high levels of illumination and UV radiation, air pollution, mould growth, insects and other pests. Although in the ideal situation all of these will be controlled, in practice it will be necessary to identify the most serious agents and concentrate on these. It is not sensible to go to extreme lengths to control mould growth if this is only found on a few objects, and at the same time the building and possibly the collections are being destroyed by termites. Following a risk assessment of the building and its contents, it should then be possible to develop a strategy for the preservation management of the collections.

The agents of deterioration are:

- direct physical forces such as from earthquakes, cyclones (typhoons/hurricanes);
- vandalism and theft;
- fire;
- water;
- pests;
- contaminants;
- light and UV radiation;
- incorrect levels and high fluctuations of T;
- incorrect levels and high fluctuations of RH; and
- custodial neglect.

There are three types of risk created by these agents:

- type 1 rare and catastrophic;
- type 2 sporadic and severe, and
- type 3 constant and gradual.

For example, fire would be a type 1 risk, insects type 2, and in hot humid climates humidity would be type 3 risk.

Following identification of the main agents of deterioration and the risks to the building and collections, in decreasing order of preference it is necessary to:

- detect the agent or its effects;
- avoid sources and attractants of the agent;
- block the agent;
- respond to the agent, and
- recover from the effects of the agent on the objects.

Obviously, if it is possible to block an agent of deterioration, such as an insect, then the remaining two stages will not be required.

It is also necessary to identify the sensitivity of the materials of works of art and artefacts to levels and rates of change, especially of T and RH, to determine if there are any special requirements for the collections. For example, if there are a few bronze and iron objects suffering from chloride corrosion, it would be sensible to separate them and store or display in an individual controlled environment at low RH, eg using a desiccant. The separation of objects and collections into material type rather than say their provenance, may make it easier for their storage and display. Most inorganic materials of ceramic, glass and stone, can safely be stored and displayed without too much regard to the museum environment, whereas metals, especially if contaminated with salt will require dry environments, and for organic materials it will be necessary to avoid very high humidities. This approach may be necessary and possible for large museums, but probably not for small ones.

For example, a small museum in tropical northern Queensland with limited resources has identified that the main risks to its collections are:

1) Cyclones: since the museum is located in a cyclone prone belt.

2) Fire: since there are no fire extinguishing or fire warning systems.

3) Relative humidity: high due to the tropical climate.

4) Incorrect handling by volunteers, causing possible damage to objects.

5) Light: due to the direct sunlight falling on photographs on display.

6) Insects.

Risk analysis prioritises the above six risks and is a valuable, logical tool in allocating resources. In the above particular situation, the museum Director decided on a three-year program:

The first year included dealing with the highest priorities, i.e. catastrophic threats from fire and cyclone, relocating the photographs to minimise light damage, implementing a regular cleaning regimen for storage areas to minimise insect damage, and purchase of a basic training manual for volunteers.

The next year's priorities included UV filters for windows to minimise light damage, purchase of dehumidifiers for storage areas, and better seals for doors and windows to prevent insect ingress.

The third year's priority included costs for museum consultants to provide training for volunteers, as well as assistance in preparing disaster and pest management policies.

6. CLIMATE, BUILDINGS, PEOPLE AND OBJECTS

6.1. Designing for human comfort

In most cases, 'new' systems or design strategies are based on well established principles of traditional building. Such vernacular architecture employs not only the characteristics of the building forms and materials in moderating the effects of environmental extremes, but also the attributes of human perception to achieve relative comfort in adverse circumstances.

Concerning human comfort, the following general principles may be stated:

- Human beings exchange heat with their environment through a complex combination of the four interdependent physical variables involving convective, radiative, evaporative and conductive mechanisms of heat transfer.

- They are adaptable within broad 'zones of comfort' in which one variable may exceed 'normal' bounds, while another compensates for the discomfort that would result.

- The human perception of thermal comfort is both physiological and psychological.

- Human beings are mobile, able to move about. They can leave one part of a space, which is uncomfortable, and move to another, which at that particular time presents more suitable environmental conditions.

The application of these principles may perhaps be best illustrated by an example:

> People in hot arid climates retreat to massive stone or earth walled living quarters during the day. These have small openings, eliminating sun from the interiors, and are sealed against excess infiltration of the hot air from outside. Limited ventilation air is passed over water, and thereby evaporatively cooled and humidified. The living quarters stay relatively cool. Exaggerated shade, and the use of planting in courtyards, aids the illusion of coolness, by contrast to the barren glare of the natural environment. If properly designed and managed, the living quarters stay relatively cool till nightfall, because of the long time lag between the onset of the day's heat and when it is transmitted by the thick walls and roof to the interior. At night, people sleep on the roof cooled by radiation to the night sky, or if too cool, warmed by the heat stored in the roof slab. Meanwhile, heat stored up during the day in the massive construction of the houses, is dissipated by throwing it open to ventilation at night, ready to start all over in the morning. This strategy is made possible by the large diurnal temperature variation of desert regions.

6.2. Designing for the preservation of objects

It will be immediately apparent that as useful as they are for minimising human discomfort, the principles of achieving human comfort and approaches such as that exemplified above have some, but only limited application to the maintenance of conservation environments for objects:

- First and foremost, objects are substantially static. Of their own volition, they cannot move away from an unfavourable environment.

- Secondly, while environmental variables are to a degree interdependent, none of the sensory compensations human beings exercise are relevant. Rather, some of those interdependencies exaggerate the potential for damage to objects. An example is the inverse correlation between temperature and relative humidity: with people, the lowering of RH as temperature rises favours comfort but it merely hastens the desiccation of wood.

  Another example would be the way people compensate for cool air temperature by seeking out radiant heat; with objects this would promote destructive differential temperatures stresses, and increase rates of deterioration.

- Because there is an overriding requirement to minimise the rate of change in the environment for objects, the potential for exploiting environmental extremes (in the manner described for the traditional architecture of hot arid zones) is limited.

- And, finally, objects take no comfort from purely psychological compensations for physical stress!

Nevertheless, we are reminded that collections of objects have remained in acceptable condition in some traditional, passively modified environments in extreme climates, whilst on the other hand, significant degradation in a shorter time has occurred in air-conditioned buildings. The challenge is to identify those characteristics of such places that have contributed to preservation, and to eliminate the harmful conditions.

It is evident that the promotion of passive environmental control is important not only from the point of view of capital cost, i.e. the establishment, maintenance and running costs of HVAC systems. It will also reduce recurring energy costs and emission of pollutants. In addition, it should encourage the design of a museum building which is in harmony with its environment, and is more likely to be culturally, technologically and environmentally appropriate to its locale, than the all too common air conditioned glass boxes seen all over the world.

It must be stressed that passive environmental control does not necessarily mean the total exclusion of some level of active control. In some institutions, specialised requirements, including the need to accommodate loan exhibitions, may make high standard air-conditioning unavoidable.

In others, the use of forced ventilation with ceiling fans or the occasional use of local dehumidifiers may be appropriate under certain circumstances, and at little cost.

The aim of passive environmental control is to work with, not against the forces of nature, and to use these to create better conditions. The building should be sited and designed to reduce undesirable environmental stresses, but at the same time use all natural resources to provide a stable indoor environment. The two fields of climatology and architecture are closely linked.

The process for designing a passive building for human comfort follows four steps in the order:

- climate;
- biology;
- technology; and
- architecture.

The climate is first surveyed and its impact on human comfort determined. Then technological solutions are developed to overcome problems, and finally the solutions combined in the architectural design for the building. If we replace the human comfort (biology) with object comfort (preservation in the museum), a similar process can be carried out for museum objects.