HERITAGE
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GUIDELINES FOR ENVIRONMENTAL CONTROL

IN CULTURAL INSTITUTIONS

Consortium for Heritage Collections
and their Environment

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The Consortium for Heritage Collections and Their Environment:

Dr Steve Brown, Principal Research Scientist, CSIRO Division of Building, Construction and Engineering

Dr Ivan Cole, Principal Research Scientist, CSIRO Division of Building, Construction and Engineering

Mr Vinod Daniel, Head, Research Centre for Materials Conservation and the Built Environment, Australian Museum

Mr Steve King, Associate Director, Centre for Sustainable Built Environment, University of New South Wales

Professor Colin Pearson, Co-director, Cultural Heritage Research Centre, University of Canberra

The diagrams were provided and drawn by Steve King

Heritage Collections Council
Collections Development Section
Department of Communications, Information Technology and the Arts
GPO Box 2154
Canberra ACT 2601
Australia

Telephone: 02 6271 1000
Facsimile: 02 6271 1800
Email: hcc.mail@dcita.gov.au
Website: *http://www.dcita.gov.au*

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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)	UV (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.

7. PASSIVE CLIMATE CONTROL FOR CULTURAL INSTITUTIONS

7.1. Passive building strategies

7.1.1. <u>The building as an environmental modifier</u>

All buildings act to modify the ambient climate. A well designed building will not only shelter its contents from the worst of the weather such as rain, wind, and hot sun but also significantly reduce the impact of extremes of temperature and humidity. A building designed specifically for passive environmental control will go further than this. By appropriate planning, choice of materials, and especially the management of ventilation, one can achieve free heating in cool climates and even free cooling in over heated climates.

A poorly designed building on the other hand, will amplify some of the climatic variables. A typical example would be some buildings in the tropics, which all too often, are hotter inside than the maximum temperatures attained outside.

In order to understand the way in which a successful building modifies its interior climate, it is useful to distinguish a number of separate mechanisms.

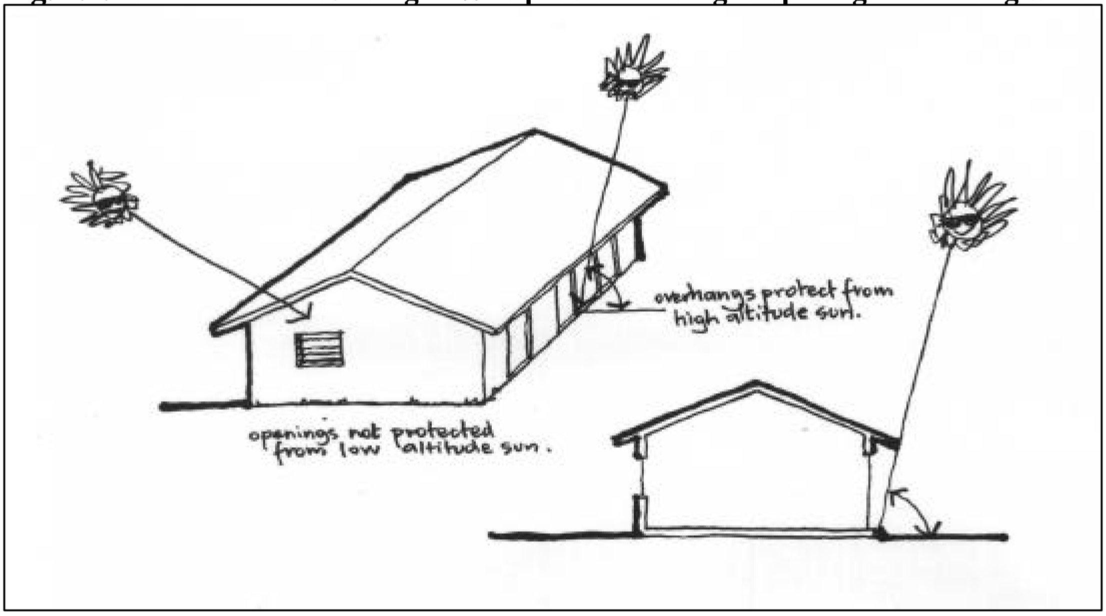
7.1.1.1. Load reduction

The first task of the building fabric is to reduce the impact of ‘climatic loads’ on the building. In hot climates, these loads are primarily solar radiation and elevated daytime temperatures. In cold climates, they are potential heat losses due to cold air temperatures, aggravated by exposure to cold winds.

In hotter climates the interior of a building would normally heat up more than the surrounding external spaces. This happens because, in addition to responding to ambient air temperatures, the building is also subject to solar radiation. While the building fabric is generally efficient at absorbing such radiation through roof, walls, and especially windows, it is far less efficient at re-radiating heat to its surroundings. As a consequence, building interiors often heat up to temperatures far higher than ambient outside at the same time. In order to avoid this happening, the first step is therefore to reduce the building's exposure to solar radiation.

The first step in reducing unwanted solar gain is to make appropriate choices of building orientation. In general, east and west facing facades receive the greatest solar loads in summer, while, in Australia, the north facade actually receives less solar radiation in summer than it does in winter (Fig. 7.1.). A simple rule is, therefore, to reduce the size of east and west facades, and to reduce to a sensible minimum any glazed openings in those facades.

Fig. 7.1. Orientation of building E-W to provide shading to openings in the long walls



Additional protection is achieved primarily by shading, reducing the solar load actually reaching the building fabric. Again, in Australia, north facades are easiest to shade, because a simple overhang will deal precisely with any chosen shading period. Employing reflective building surfaces further reduces the radiation absorbed buildings in warm climates should therefore be generally light in colour. In addition, ventilation is often employed to remove excess heat build-up in the interiors.

It should be stressed that simple load reduction only serves to achieve an interior climate in a building, which is perhaps no worse than the ambient climate. This is particularly true in warm humid climates, where buildings with copious cross ventilation could be said to be no more comfortable than sitting under a shady tree outside.

In cold climates, load reduction is limited to reducing the exposure of the building to such influences as prevailing cold winds. This is achieved by appropriate siting, shelter planting, and a compact building volume with a minimum surface to volume ratio.

7.1.1.2. Insulation

The ability of the building to transmit heat in response to external loads may be modified. This is achieved by increasing the resistance of the building fabric to heat flow; in practical terms by adding insulating materials. This strategy is most beneficial in artificially heated or cooled buildings, because it conserves the energy inputs in the heating or cooling system.

Insulation, especially of roofs, is also a vital part of passive design. However, under some limited circumstances, over-insulation is actually counter-productive. This can occur when shading in hot climates is ineffective, and the insulation actually impedes removal from the building of the excess solar gains.

7.1.1.3. ‘Flywheel’ effects

Appropriately designed buildings will dampen the impact of daily extremes, of both ambient temperature and humidity. Thus, in an over-heated climate, a building interior might be cooler than ambient during the day, and warmer at night. This is achieved mainly by appropriately deploying thermally massive materials, in order to store and release heat. Overall, the building serves to bring interior conditions to a narrower range throughout the day, closer to the average conditions outside. It should be noted that in a cold climate, the same would be true.

Such thermal flywheel effects are generally successful in hot arid climates, where, because of the very large diurnal temperature range, daytime temperatures are too high, and overnight temperatures may well be below comfort levels. When the average temperature for the whole day is in an acceptable range, and if the building achieves a small enough ‘temperature swing’, little other climate modification may be necessary. Clearly, in the under-heated climates, interiors may still end up too cool throughout the 24-hour cycle of the day.

Again, it should be emphasised that dampening thermal fluctuations, while generally beneficial because it achieves more stable environments, achieves no overall cooling in an over-heated climate, nor net heating in an under-heated one.

Humidity variations are also generally smaller inside buildings than outside on the same day. The rate at which interior humidities respond to the ambient is largely determined by the rate and amount of air exchange between the outside and a building interior. In addition, by appropriate choice of materials for their ability to absorb and desorb moisture, a certain degree of humidity buffering can also be achieved (section 9).

7.1.1.4. Selective natural heating or cooling

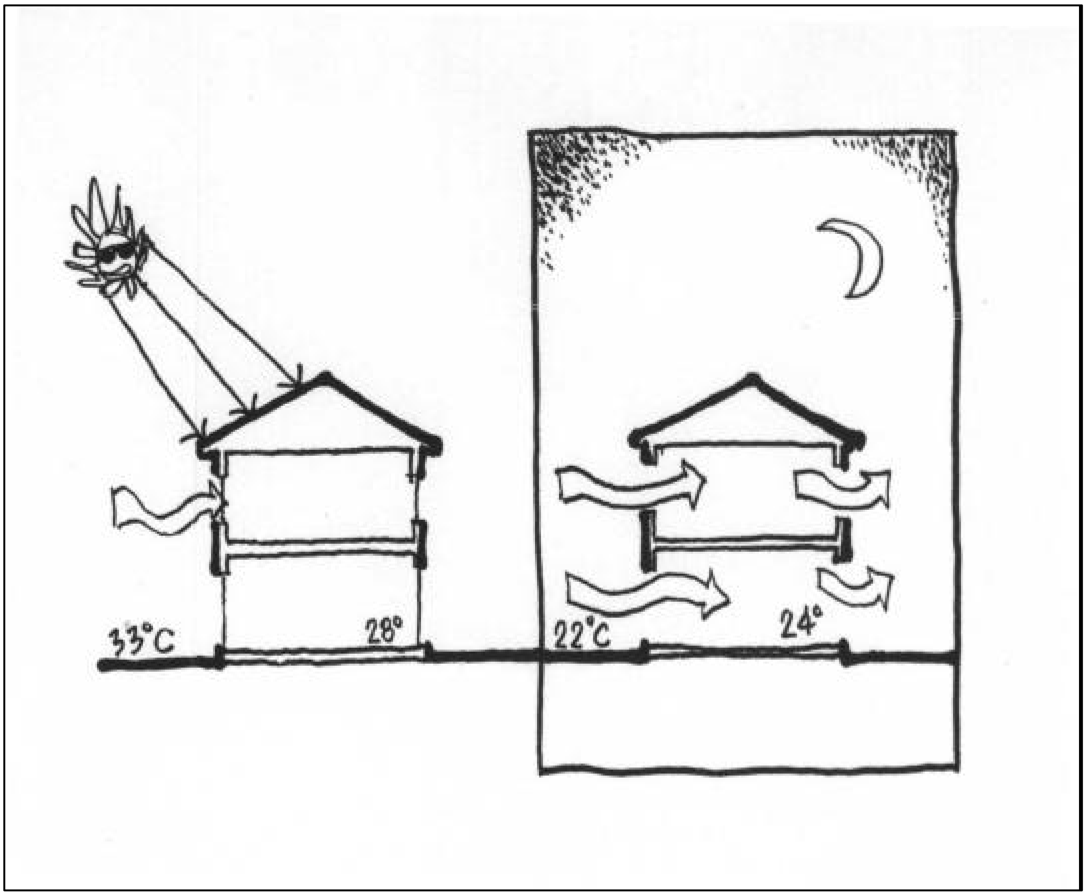
By good design, it is possible to go further than simply reducing extremes, and thereby merely approaching average ambient conditions. To determine whether net heating or cooling is achieved, it is necessary to compare *daily average* temperatures achieved over a period inside, with those outside for the same period.

In an under-heated climate, passive solar design employs orientation for solar gain, insulation to reduce heat losses, and thermal mass for storing admitted heat. By admitting solar gain through glazing, storing it in the ‘over-heated period’ and releasing it at night, it is relatively easy to achieve an interior that is, on average, warmer than the ambient conditions outside. In cool temperate zones, it is theoretically possible to achieve a ‘solar heating fraction’ i.e. the contribution of solar gain to the total heating requirement of a building approaching 100 per cent.

In hot arid climates with large diurnal temperature variations, a combination of shading, thermal mass, and controlled ventilation, can be used similarly to reduce internal temperatures.

Thermal mass in the *exterior* building fabric slows the heat flux such that some of it reverses as the exterior cools, and is given off at the exterior rather than the interior surfaces. *Internal* mass absorbs heat during the overheated period, and is cooled by night ventilation. In a hot arid region, a well designed building with a well managed 'night flush' ventilation regime, can expect to reduce daytime maximum temperatures by 40 60 per cent of the diurnal range (Fig. 7.2.).

Fig. 7.2. Night ventilation



Average internal temperatures are more difficult to lower, but monitored results from such buildings in California and Israel have shown a reduction to approximately 1°C below the ambient average. This result should be compared with a 'closed' thermally massive building, which would expect to achieve an internal average approximately 3°C above ambient.

In warm humid climates, because of the small diurnal variation in temperature, such net cooling is very difficult, indeed often impossible.

7.1.2. Building elements and systems

Building elements and systems may be classified according to a number of different considerations. Most commonly, we would discuss the building under the headings of floor, walls and roof. Alternatively, it might be useful to distinguish structural elements (those which hold the building up), from cladding (elements which keep the weather out). For the purposes of this discussion, however, building elements will be primarily classified according to functions they perform within a broad environmental control system.

The building as a whole acts as a filter, or modifier of the environment. Under the concept of filter, we can discuss how the various external environmental variables, radiation, convective heat gain/loss, and air exchange are controlled by the external fabric of the building. Under the more general concept of modification, we can discuss the time dependent effects of heat storage and moisture buffering.

Such a conceptual understanding of the role of various components of the building fabric allows an informed discussion of the choice between passive and active environmental controls, and the impact of such choices on other aspects of the building design.

7.1.2.1. Conductive heat loss/gain

Heat flows into and out of buildings through the elements of its external envelope. The main mechanism of heat flow is conduction, the method of transfer of heat where atoms can pass their vibration energy to adjacent atoms in the lattice structure of a solid material. Strictly speaking, conduction can only occur in a homogeneous element, such as a solid brick wall without cavities, whereas practical building materials are made of usually more than one material, have to take up heat from air and give it out to air again, and often have air gaps inside the construction.

So heat loss or heat gain through a building element is determined by the:

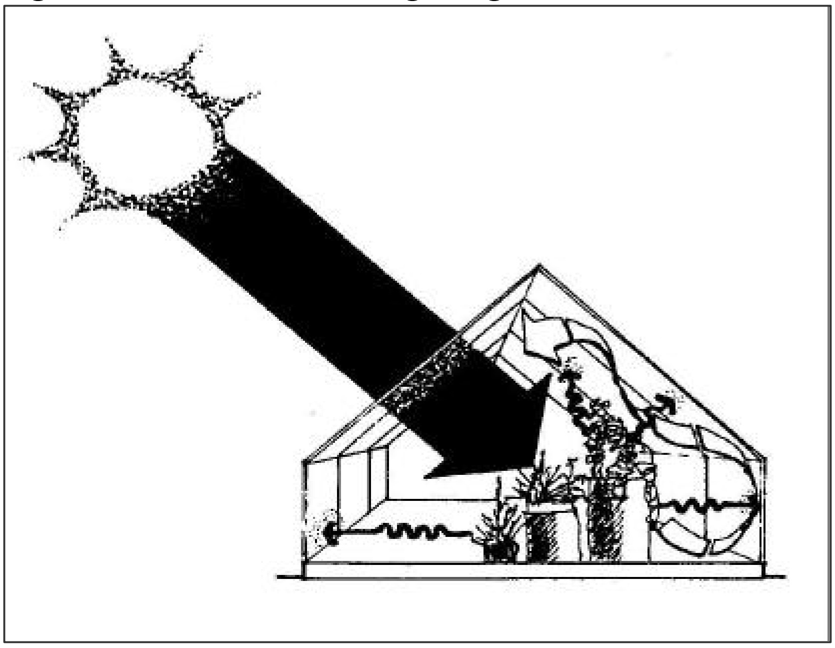
- the area of the element;
- the air speed either side of the element;
- the resistance (R-value) to heat flow of the individual materials;
- the resistance to heat flow of the air spaces (including the ability to transfer heat from a material to the air, then back to another material); and
- the *effective* temperature difference, allowing for radiation effects.

7.1.2.2. Solar radiation and transparent building elements:

Transparent building elements are characterised by the fact that they *transmit* a high proportion of the radiant energy unchanged from one side to the other. The most common transparent building material is glass. Previously, other materials had been used, such as mica, parchment, paper and thin stone panels. These days we also use various plastics, as rigid or flexible sheets.

Conventional soda glass has a particular characteristic that distinguishes it from most other transparent materials. Glass is transparent to all radiation in the solar spectrum, but is substantially opaque to radiation above approximately 3#100 nm (section 3.3). This gives rise to the so-called *glass house effect* (Fig. 7.3.)

Fig. 7.3. Glasshouse effect of glazing



Glasshouse effect. Incoming solar radiation passes through the glass. On striking any surface in the occupied space, the solar radiation is absorbed, thus heating that surface. As the surface (whether it is a wall, floor, furniture, or any other object) heats up, it re-radiates energy, but now at the longer wavelengths. However, the glass is opaque to such longer wavelength radiation, trapping the radiation inside the space. The net effect is that the interior continues to warm up. This is the basis of all passive solar design.

By applying various films to the glass we can balance the transmission characteristics for different parts of the solar spectrum. For instance, an ideal *sun control film* will keep out most of the infra-red, and admit a particular fixed desirable level of the visible spectrum. In contrast a so-called *heat mirror* (the sort of glass ideal for passive solar applications) would admit maximum visible and near infra-red, and be completely opaque and reflective for longer wavelength infra-red radiation. Various additives and films can modify the properties of glazing systems in different ways. Broadly, we have heat absorbing sun control glazing, reflective sun control glazing, and glazing that has its emissivity modified. Increasingly these days, for larger institutions there is merit in considering ‘advanced glazing systems’, which can combine various of these characteristics to achieve heat, light and spectral distribution control characteristics, closely matched to the particular application.

For smaller and passively controlled environments, it is still more fruitful to turn to other, perhaps operable ways of shading the glazing in a building. Obviously, it is better to stop the radiation from reaching the glass in the first place. For this, external devices are the most effective. But internal elements can also work. If we can reflect as much short wavelength radiation as possible as soon as it has entered through the glass, much of it will go straight back out through the glass, and only a small part will be trapped inside. Thus, for instance a dense white roller blind can achieve a shading coefficient of 0.6 even though it is applied at the inside of the glazing.

7.1.2.3. Heat storage and time lag effects

As a material absorbs heat, it warms up. Typically, dense heavy materials are effective at storing heat, while light materials are not so effective.

Periodic Heat Flows. To warm up a particular volume of material, heat must travel inwards from the outer surface of the block, progressively warming up each incremental layer. For the material to give up that heat, the direction of the heat flow must reverse. Heat flows from warmer to cooler material, so this cycle of inwards and outwards flow assumes that the outer layers will vary, from warmer to cooler than the core of the heat storage element.

There are two quite different situations applicable to buildings:

- Heat flows *through* a material typically a solid external wall. The storage of heat in the material causes a *time lag* between initial heating, and the arrival of the peak heat 'wave' at the inside face of the building element.

- Heat flows into, and back to the same face of an element typically the thermal mass stores heat from one part of the day, and gives it up at a later, cooler time of day.

These two cases are fundamentally different. In the first case, a thermally conductive wall of designed thickness (the thickness depending on the delay required) is located on the external walls. The second case is usually an inside element, insulated from the outside, where surface area exposed matters, and only limited thickness is useful.

We would be interested in the first situation, as described previously, in hot climates with large daily variations in ambient temperatures. Roofs and walls can be readily designed to achieve typically five to eight hours ‘lag’ in order to minimise incoming heat loads during a typical day.

Most of the time we are concerned with the second type of heat storage, where heat enters (typically) a concrete slab floor, when there is excess energy coming into the space. The slab is warmed up. Later, when the air temperature is lower than that of the surface of the slab, the heat then flows back out.

This latter type of heat storage is a key component in *passive solar design*, where the excess heat is deliberately admitted into the building, usually by way of appropriately oriented glazing. The excess heat is taken up by the thermal mass, which warns up in the process. As the spaces cool down in the evening and at night, the heat is given up again by the thermal mass, thus limiting the so-called temperature swing of the contained spaces.

As described in the previous section, heat storage capacity in the space is also useful to moderate the effects of unwanted heat transmission from the outside, such as in hot arid climates. The principle of storing heat during the day, and giving a back up at night is identical; but the role of the external fabric changes to keep out heat during the day, and get rid of it at night by ventilation.

7.1.2.4. Ventilation and air exchange:

Air quantity or air velocity? When discussing ventilation, two types must be distinguished. One is the simple supply of 'fresh' air, coupled with the removal of 'stale' air. This type of ventilation is conventionally specified in air changes per unit time. Alternatively, it is prescribed in building codes on the basis of litres/second per occupant. Air change is required in order to achieve a dilution of the build-up of internally generated contaminants, and serves also to remove sensible heat.

Air changes also occur as adventitious infiltration or exfiltration. Even in extremely well detailed buildings, conventional building practices compromise the integrity of the building fabric. Small air paths through the construction are inevitable, most particularly around openings. In fully air-conditioned buildings positive pressurisation will usually assure a small, but steady outward flow of conditioned air.

Additional air exchange occurs as a consequence of the use of the building, through the necessary use of entrances, for both people and goods. In some circumstances, a ‘closed front door’ policy (e.g. using revolving doors at the museum entrance) can limit air exchange with the exterior to a significant degree.

A second type of ventilation is utilised to generate certain surface conditions, such as evaporation from the skin, and is therefore specified in terms of air movement. It may be provided by enhancing natural breezes, or by mechanical means such as fans. In order to be effective, the air stream must pass over the occupant or object. The higher the air velocity, the more effective such ventilation, but a practical limit is imposed by damage or nuisance value. It should be self-evident that any building whose ventilation is strongly linked to the outside will, by definition, be less effective as protection against air pollution than one in which ventilation is controlled.

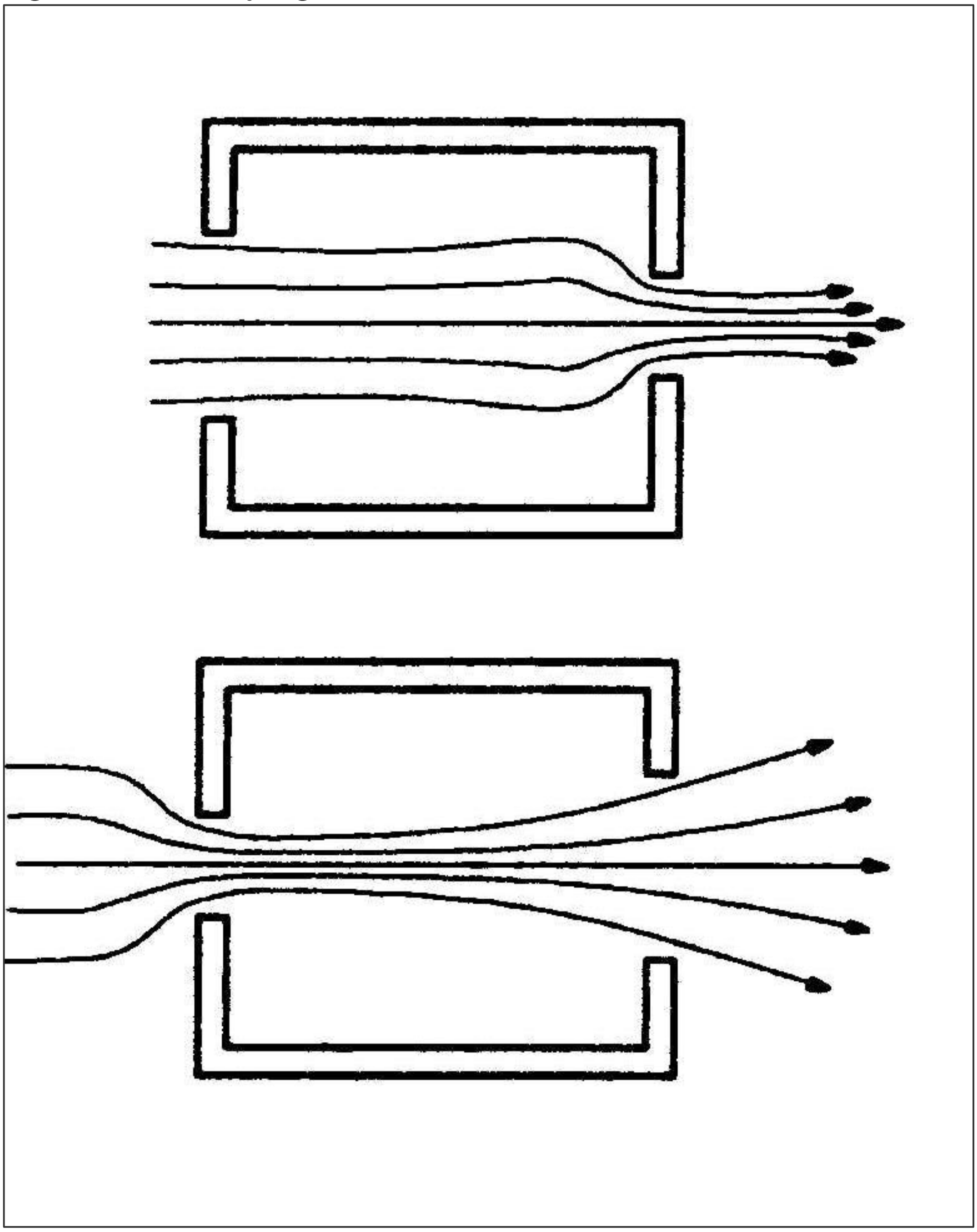
Determinants of airflow for comfort ventilation. The problem of summer comfort in warm humid regions requires that breezes must pass through the building to remove any build-up of warmed air, particularly under the roof and ceilings. In addition, the airflow must pass over occupants, at sufficient velocity to aid in the evaporation of perspiration, and so extend the perceived comfort zone to higher temperatures. Similarly in a museum, airflow must reach all parts of the space to aid mould control on collections. Building and landscape design should direct air movement in desired directions, and often enhance the available velocity of the available breeze.

Determinants of air velocity. The principles are best illustrated by reference to a simple building plan or section. Firstly, to have effective ventilation, an outlet as well as an inlet is required. The factors which then affect the speed of airflow through the building are:

- the ratio of outlet to inlet opening sizes; and

- the degree of obstruction to the flow.

Fig. 7.4. Air velocity is greatest when the inlet is smaller than the outlet

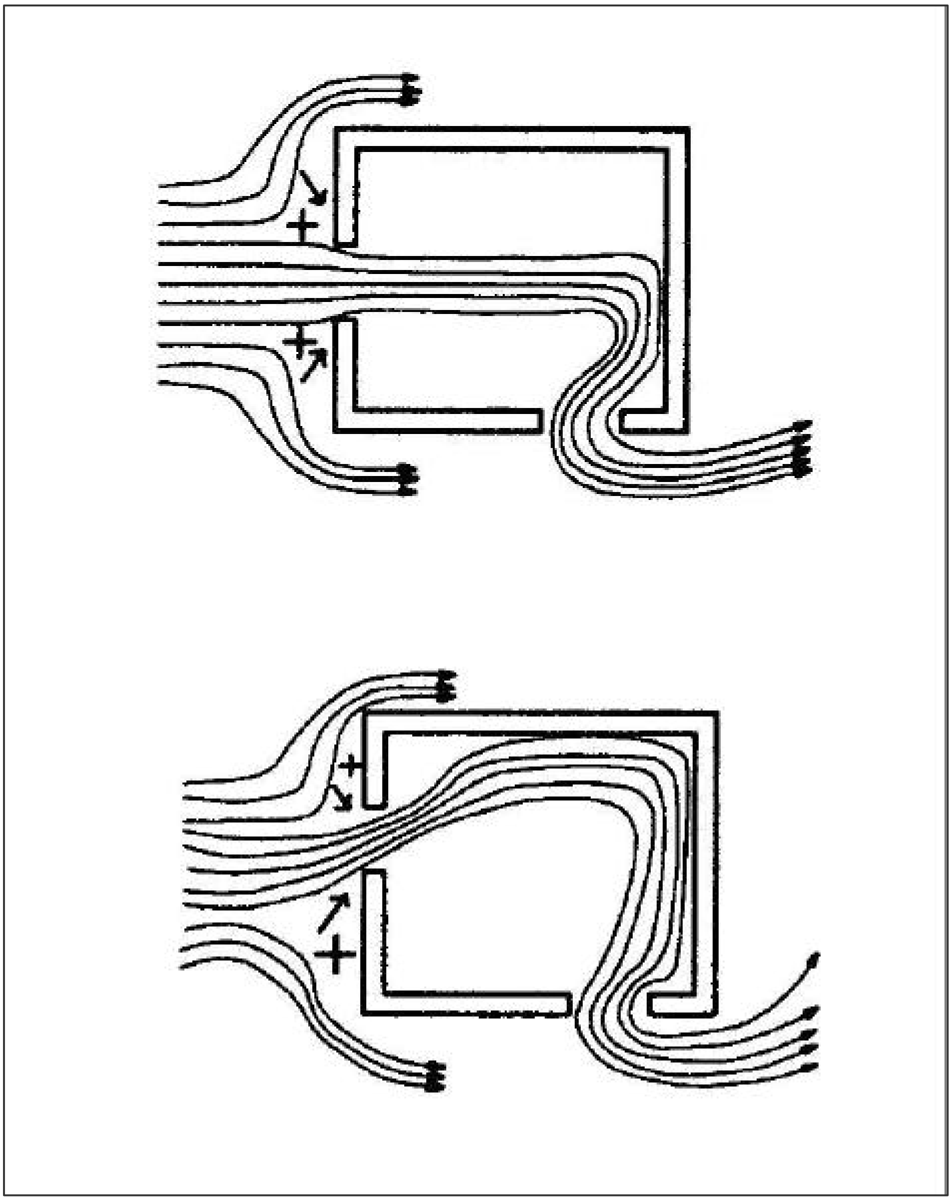


For maximum air speeds within the building the outlet should be greater than the inlet (Fig. 7.4.). This situation is analogous to the spillway of a dam through which the water rushes from a lake that is hardly moving at all. When the inlet is larger than the outlet, this spillway effect is outside the room, whereas when the inlet is smaller, it occurs within the room.

Determinants of airflow direction. Moving air has momentum and will keep moving in a particular direction until turned by pressure differences. This makes the motion of air very difficult to predict in detail but some practical approximations may be derived.

Note in the diagrams (Fig. 7.5.) that the airstream continues some distance into the room before turning to seek the outlet.

Fig. 7.5 Airstream direction is determined by the position of the inlet opening



In addition the direction of air entering a room is 'steered' by pressure difference between the two sides of the opening. In the top diagram (Fig. 7.5.), the pressure distribution on the windward facade is approximated. On the lower diagram, an asymmetrically positioned opening will have a more elevated pressure on one side of the inlet opening, than on the other. This pressure difference influences the direction of the incoming stream of air, as shown.

This effect may be used to ensure that air movement occurs where it is required, for instance near the floor in the occupied zone of the room. Attention therefore must be given to the location of the opening in the facade, and the design of window surrounds and secondary openings, which may modify the pressure distributions. Where the location of openings in the facade cannot be determined by these considerations, the air distribution in the room may need to be solved by physical deflection of the air-stream at the window plane, such as by louvres.

The location of outlet openings is not critical, as long as they are in an area of lowered pressure. The maximum air speed is obtained when the airstream does not lose too much momentum by many abrupt changes in direction. This is the basis of the requirement for 'cross-ventilation' in traditional architecture for warm humid climates. Cross-ventilation favours simple, one room deep plans.

Air quality. Low levels of outdoor air supply (whether natural or mechanical) to minimise the intrusion of urban air pollutants needs to be used judiciously in each building, according to:

(a) the degree to which levels of urban air pollution are high;

(b) the presence of indoor pollutant sources, which may lead to high indoor pollutant levels at low ventilation rates; and

(c) the level of occupancy of the building, from the perspectives of both supplying sufficient 'fresh' air for the health and comfort of occupants, as well as removing pollutants generated by occupants themselves.

The degree to which building ventilation can be reduced might be generalised according to the level of carbon dioxide (exhaled from occupants) achieved in the building. Outdoor carbon dioxide levels are typically 400 ppm. One guideline used by many building authorities is that if indoor levels exceed 800–1000 ppm maxima during days of occupation, ventilation is inadequate for health and comfort relative to the number of occupants.

7.1.2.5. Building elements as moisture buffers

Most building materials are porous and/or hygroscopic and store large amounts of water. In fact, the quantities of water that building materials store are hundreds of times greater than the quantities of water vapour contained in the air which the materials surround. A building typical of a historic house museum may contain 5kg of water in the enclosed air, and 2#000kg of water in the building materials.

The use of porous materials in walls and ceilings is an unappreciated aid to maintaining constancy of relative humidity indoors and deserves the attention of architects and engineers. Hygroscopic walls and ceilings give substantial stability to the indoor relative humidity (RH) in rooms which are ventilated at less than about one air change per hour. A few centimetres of material are sufficient to buffer the daily RH cycle, about 40 cm of wall will buffer the annual cycle of RH in a room with about 0.1 air changes per hour.

The implications are obvious. At the scale of buildings, or in the case of store rooms housing a significant amount of organic material of large surface area, the relative humidity of the air will be dependent on the moisture content of the materials, rather than the other way around. Furthermore, if such spaces have limited opportunity for exchange of air with the ambient environment, the relative humidity will be buffered by the objects contained, because the materials will desorb water with rising the temperature. Temperature changes are a greater force in determining moisture content than humidity changes in the surrounding air.

Clearly, therefore, humidity buffering by building materials is a key phenomenon in passive environmental control for museums. Unfortunately, no research on humidity buffering in warm climates appears to have been undertaken to date.

7.1.2.6. Natural light

The effect of light on stored and displayed objects is well documented, and is discussed in section 3.3. Illumination levels required for storage are governed only by the requirement for working with the materials in question. General lighting may therefore be quite low, and supplemented by intermittent artificial task lighting. Lighting for display poses greater difficulties, and the discussion of architectural control of illumination appears to be the subject of fashion as much as reason (see also sections 10.1.2. and 10.2.2.).

The levels of 'safe' illumination for most materials are very much lower than the externally available natural light, which in addition contains excessive UV components (section 4.2). However, to more usefully discuss natural lighting, it is important to distinguish between sunlight and daylight.

Sunlight is several orders of magnitude higher intensity than light from other parts of the sky. It probably has no place in any part of a space used for the conservation of sensitive materials. This applies to some degree even to reflections from sunlit surfaces, whether within or external to such a space. In warm climates, the coincidence with the need for shading for thermal control should make exclusion of solar radiation an absolute requirement.

Daylight is light from the remainder of the sky hemisphere, excluding the sun’s disk. Daylighting may be usefully deployed in even sensitive display areas, and aversion to it is probably unreasoning paranoia on the parts of some curators and conservators. Daylight is the most economical source for general illumination of the building interior and is of generally favourable colour balance for the display of most objects. Even when examined in terms of control of associated heat loads, it has a higher luminous efficiency (lumens/watt) than almost all artificial sources.

Daylight admitted by conventional windows falls off in intensity so rapidly with distance from such openings (the 'inverse square law' dictates that doubling the distance quarters the illumination level), that limitation of illumination to given 'safe' levels is largely a matter of display layout. The fast decay of daylight levels from openings to interiors may itself be used to differentiate circulation from display areas, and to assure levels of general illumination to avoid impressions of 'gloom'.

Simple reflections of daylight by white painted surfaces remove over 80 per cent of all harmful UV components. Of course, lux levels are also reduced by the reflections, but in approximately the inverse proportion. If a guaranteed double reflection can be arranged, the resulting illumination will have UV/lux ratio reduced to approximately 1/16 that of the original daylight.

In principle, this means that as long as exclusion of sunlight is guaranteed by a combination of orientation, shading and detail design, and daylight is admitted by openings designed to achieve reflection off painted surfaces, then buildings may be designed to exploit daylighting for display without compromising conservation requirements, and without resort to expensive and degradable filters.

7.1.3. The principle of ‘layered’ control

As mentioned previously, there are some limits to the application of passive environmental control to conservation objectives, especially in hot humid climates. However, in all climates, the extremes of the external environment can be progressively modified.

The principle of 'layered control' is well known to curators and conservators, and is usually applied in museums for the progressive reduction of RH variation or air pollutant concentration as you move from outside, to interior space, to showcase. It relies first and foremost on restricting the degree of air exchange between each 'layer' of space, with the rate for a showcase measured in changes in a day, rather than air changes per hour.

The same principle can be applied to all environmental variables to some degree, except that other variables than air exchange are also employed. Each of the following constitutes an incremental layer of protection:

- appropriate siting;
- reduction of loads on the building;
- layout planning to place the least vulnerable spaces to the greatest exposure, in order to 'isolate' rather than 'insulate' vulnerable spaces; and
- the use of local controls, such as showcases or other microclimates.

These principles are the framework of passive design strategies for different climates, described in section 8.

7.2. Control of pollutants, mould and pests

7.2.1. Air Pollution

7.2.1.1. Removal of outdoor air pollutants:

Institutions with mechanical ventilation systems have two options for control of outdoor pollutants that ingress the buildings: (a) selection of interior surfaces that react with pollutants or (b) minimising the intake of (polluted) outdoor air. These two factors work together (i.e. as ventilation rate is reduced, proportionally more of the pollutants can react with surfaces) and it is expected that optimum pollutant reduction will balance these effects with the requirements of air supply to building occupants.

Certain interior surfaces are known to react more with oxidant pollutants; for example sulphur dioxide, nitrogen dioxide and ozone are best absorbed by wool carpet, then in decreasing order; wallpaper, latex paint and least by metal or glass.

The effectiveness of reduced intake of outdoor air on indoor levels of urban pollutants will be dependent on the nature of interior surfaces in each building (as well as the tightness of the building envelope) and so it will be difficult to generalise the required degree of ventilation reduction.

7.2.1.2. Controlling emissions of indoor pollutant sources:

Air pollutants arise in buildings from a multitude of pathways, but these are predominantly the following:

(a) ingress of pollutants from outdoor air with air used to ventilate the building or which infiltrates the building through its (leaky) envelope;

(b) emission of pollutants from building materials, furnishings and fittings used inside the building; and

(c) emission of pollutants from appliances (eg. office equipment, heaters) used in the building.

Other sources can include pollutants emitted from the occupants themselves and their activities (e.g. odours, certain volatile organic compounds, bacteria, moisture) or pollutants associated with poor building practices (e.g. inadequate cleaning, ventilation below standard requirements, ongoing condensation on interior surfaces such as air-conditioning ducts and plant or some walls).

Building materials and furnishings are significant sources of indoor air pollutants such as formaldehyde and volatile organic compounds (VOCs).

Removal of air pollutants is discussed in section 10 dealing with display cases and storage units.

7.2.2. <u>Mould</u>

When considering the growth of fungi, which causes mould, it is necessary to examine the substrate on which they grow. It is here, in the surface layers and immediate air layers surrounding the material, that the relative humidity is important.

Another property of organic materials, the equilibrium moisture content (EMC), provides a measure of the amount of water held by the material, but does not indicate how much is available. Different materials absorb and desorb moisture at different rates, and when at equilibrium with the surrounding air, at a given RH of the air they will have different equilibrium moisture contents. For example, leather is higher than wood which is higher than wool and cotton. With a certain fungal species, mould will grow on leather at 76 per cent RH, on wood or wool at 85 per cent and on cotton at 96 per cent RH.

Due to the small diurnal changes in temperature in hot humid climates, the use of air movement and ventilation will have little effect on the temperature, and therefore the use of heat (increase T with resultant decrease in RH) is not an appropriate means of lowering the RH around an object and its mould growth potential.

Mould growth should not be a problem in hot dry climates as the relative humidity will in general be too low. When cool air is brought into the museum during the night, although this will have a higher RH than the daytime air (kept out by sealing the building), when this strikes the still warm interior surfaces the RH will be lowered. So here there is the opposite problem, ie low RH levels and possible desiccation of objects.

For temperate climates there can be low or high levels of RH depending on the location and time of the year, and mould growth is a potential problem.

From the above it can be suggested (as positive evidence is not available) that in hot, humid and temperate climates, if it is possible to bring into the museum air of an RH of 70 per cent or lower for say at least one hour per day, in most cases this should be sufficient to prevent the growth of mould. This period would normally be during the day, and external climatic data at the museum site is required to determine what is possible. Air intake fans to the museum could be connected to a humidistat to take in air when it falls below say 70 per cent RH, or museum staff could be asked to open windows and turn on fans when the RH was appropriate. Care should be taken if the building is shaded or of massive construction as the temperature of the internal walls may be lower than that of the incoming air, in which case the RH at the surface would be increased, nullifying the process. Normally air would be taken in during the day, not at night as being cooler would have an even higher RH.

If mould is found, the source of moisture must be determined, as if from a leaking roof, condensation or rising damp etc., this can then be rectified. If mould still persists then other means of reducing the RH as discussed in section 8 should be considered. Fungicides should only be used as a last resort.

7.2.3. <u>Pests</u>

Insect Pests can be a major problem for museums, archives and libraries. Even with repeated treatments for insect infestation, if an appropriate and safe environment is not provided for its storage or display, the insect problem will re-occur. It is therefore important for the museum personnel to develop an Integrated Pest Management Plan for preventing the insect problems from re-occurring (section 7.2.3.1.). It could be a number of simple, practical steps to start with, which eventually can be improved.

7.2.3.1. Integrated Pest Management

It is always preferable to avoid an insect problem than to deal with it once a problem occurs. An overall IPM approach will be the best alternative. This program does not depend on the use of pesticides to prevent or control insect problems, but instead involves the implementation of a number of measures including:

(a) Physical Control: the alteration of the environment by physical means making it hostile or inaccessible for pests. For example, insect screens, seals around doors (section 7.2.3.3).

(b) Cultural control: the manipulation of the pest's environment to make it less favourable. This can include relative humidity and temperature control, good housekeeping etc.

(c) Control without using pesticides: eg freezing, heating or low oxygen treatment of insect infected objects.

(d) Monitoring and evaluation of the effectiveness of the treatment.

(e) If unsuccessful, use chemical control: appropriate selection and application of least harmful pesticides.

(f) Monitoring and evaluation of the program.

The first line of defence against pest infestation must be the building, then the display case or storage unit. All objects brought into a museum should be carefully inspected to determine whether insects or other pests are present. This may be simple for metals, glass and ceramics, but difficult for complex organic objects, natural history specimens and where packing materials have been used. If possible these objects should be left in quarantine (establish an insect-proof room for this) to determine if there is any sign of insect activity. To be on the safe side it would be better to treat them on the assumption that they do contain pests, using one of the recommended procedures mentioned above. If these practices are not carried out, any form of pest control at the building level will be a waste of time it will help to keep pests in the building, brought in from outside.

7.2.3.2. Insect traps

One of the most valuable tools of an IPM program are regular, thorough inspections. During inspections many insect problems can be discovered before too much damage has occurred. Inspections can, however, be time consuming, especially in large collections where the organic, and even some of the inorganic, material is at risk from insect attack. It is here that insect traps can be of assistance.

Blunder traps are non-specific traps which assist in identifying any insects present within the collection. In spite of the presence of a food attractant in most traps, the capture is largely due to the location and placement of the traps where insects are common. The most common traps are usually made from a piece of cardboard, one or both sides of which are sticky, but lots of other types are available.

Trapped insects can be identified using one of the many insect identification books which are available or by contacting the entomology department of a museum. Through correct identification it is possible to learn whether or not the insect poses threat to the collection, what type of material(s) are likely to be infested and what to look for (ie: adults or larvae).

Many traps now incorporate a pheromone. Pheromones are chemical messengers, similar to hormones within our bodies, which are produced by insects to communicate messages. These chemicals when passed from one insect of the same species to another, cause a certain response, either behavioural or physiological. Some examples of these are :

- aggregation pheromones, which may attract both males and females (e.g.: to a food source);
- -trail marking pheromones (such as those used by termites and ants); and
- -sex pheromones (which cue for mating).

Pheromones are now used in many traps as an attractant to lure insects into them. Any insects within a certain distance of the trap will 'home' in on the odour and will become trapped. By checking these traps on a regular basis it is possible to get an indication of the presence (or absence) of a specific insect within the monitored area. Pheromones are now available commercially for a number of insects including museum pests such as cigarette and drugstore beetle, common clothes moths and cockroaches.

7.2.3.3. Control of insects

There is a wide range of insects that can be a problem for collections including beetles, moths, termites, cockroaches, and silverfish. Some fly, others crawl, they have different life cycles and there are different species and sizes of insects. This makes it difficult to use a standard approach to any preventive system. Insects require food, water and shelter for survival and a museum can provide all of these.

First, it is important to determine the species and habits of insects that are likely to be present in a museum. Such information should be available from a nearby Forestry Commission, entomology department of a natural history museum, university or Department of Agriculture, or from commercial pest control companies. This can be supplemented by a careful survey of the inside and outside of an existing building, plus the use of insect traps to determine which insects are present. Then by studying the different insect species, their life cycles and habits, it is possible to propose a number of general and specific approaches to prevent them from entering the building.

Building surrounds

Do not plant trees or shrubs close to a building, and use non-flowering plant species. Remove ivy and any other form of creeper from exterior walls. Gravel or paving close to the building avoids the need for watering, which in turn keeps moisture away from the building and in addition it is non-attractive to insects and rodents. Leaf litter, tan bark and other organic mulches can harbour insects, therefore good garden hygiene and maintenance is essential. Obviously all garden rubbish must be kept well away from the building and removed or disposed of as soon as possible.

Buildings are often illuminated for aesthetic or security purposes. This can be a problem. If at all possible do not attach lights to a building as any light will attract insects. Close to a building the lights, if used, should be sodium lamps, which through their low UV output are not very attractive to insects. Away from the building use mercury vapour lamps, which due to their high UV output will draw insects away from the building.

As with garden refuse, garbage from the museum should be contained away from the building in a unit that is insect and vermin proof, and again disposed of as quickly as possible.

Planting and landscaping

There is a wide range of trees, scrubs and herbs which have insecticidal or insect repellent properties. If appropriate to the gardens and landscape around the museum (this may not be possible with an historic house museum and with historic gardens etc), a selection of such plantings could be included. A list, using their common names is given below:

Cotton lavender (*Santolina*) Lavender	Both plants are reputed to repel moths, carpet beetles and silverfish.
Neem	This plant is a native of western Asia where its insecticidal properties have been known for some time. It acts as a repellent and a natural Insect Growth Regulator, which disrupts insect growth and moulting. Registration for Neem in Australia is still pending.

Rosemary	This common culinary herb has a long history, as early as the 11th century, for its repellent action on many household pests. The plant itself is a repellent, not just the commonly used herb sachets.
Pyrethrum Daisy Feverfew	A plant with a long history of planting and refining for its repellent and insecticidal properties. Feverfew has similar properties to Pyrethrum, although the active ingredient is weaker.
Western Red Cedar Redwood Jam Acacia White Cypress Pine	These trees are recommended as resistant to termite attack.
River Red Gum Blackwood Bloodwood Blackbutt	These trees, as well as the above, are resistant to some extent to borers.

Wattles are the least favoured species for planting in the grounds of a museum as they are very prone to insect attack.

Building layout

Careful thought given to the layout of the building as regards its different functions at the design stage makes it possible to build it for insect control. For example, keep areas attractive to insects away from the collections whether in storage, on exhibition or with curators/conservators. The areas that attract insects are kitchens, restaurants/cafeterias, workshops (particularly carpentry), bathrooms and toilets (source of water). If possible all food processing and serving facilities should be in a separate building or at least confined to one area of a single building with direct access from outside.

It is important to have a quarantine room where collections are held on arrival at the museum, or after treatment for insect infestation. This should be adjacent to the loading bay. Making the loading bay insect proof is a challenge. Obviously doors should be closed as much as possible, and a positive pressure within the bay, pushing air out, may be of some assistance. Weather strips across the bottoms of doors would also be of benefit. The laying of a residual insecticide such as boric acid plus silica dust across an entrance to help keep out insects is a possibility, but this is questionable as they will rapidly get bridged by local foot or vehicle traffic.

Entrance doors are the other main avenues for insect entry, therefore, they should be kept closed as much as possible. Although more expensive, revolving doors or a double set of doors are useful in this regard. They also prevent loss of conditioned air (by whatever method) from within the building, or entry of heat/ humidity/dryness from outside.

Building fabric

If the materials of construction of the building are insect proof such as brick, stone, concrete or steel, then the likelihood of insects entering the building are drastically reduced compared with wooden structures, for example.

The problem with all buildings is that they have entrances and holes through which services such as electricity, water, sewerage, gas, etc., are supplied. These provide ideal access for insects which take advantage of different types of hiding places, from tiny crevices to large spaces. The benefits of these hiding places are two-fold; they provide concealment which can allow quite large populations of insects to develop unnoticed and renders them difficult to find, and the protection afforded makes eradication of insects, by whatever method, more difficult.

Doors should be kept closed at all times when not in use, and weather/draft excluders provided, not only to keep out the weather but to help exclude insects. Windows when closed should fit tightly, and if opened should be screened against insects.

Fly screens are readily available. From the literature the minimum sizes of holes to prevent entrance by different insect species are as follows:

2.3mm	House flies, blowflies
1.15mm	Mosquitoes
0.85mm	Sandflies
0.7 1.7mm	Beetles (depending on the species)

These can be controlled by the common mesh sizes of 10 20 gauge, which have apertures of 2.27-0.853mm respectively. There may still be insects such as species of the dry wood termite and wood boring insects which are smaller, and known to get through standard fly screens.

Screens should be an important feature for windows, especially in office areas that are left open to allow air movement by prevailing winds and natural ventilation. Screens should also be applied to all vents and drains through which insects could gain access to the building. Such screens will keep out all pests, but may need to be of a stronger material, or be covered with a wide mesh metal screen to exclude vertebrate pests.

All joints of the building and spaces around pipes and ducts should be carefully sealed with a flexible caulking compound. This will not only prevent insects entering the building but will remove breeding spaces, and in addition reduce entrance of outside air with its changes in temperature and relative humidity. Ideally the building should be as tight as possible.

Gutters and down pipes should be external to the building. Here building design is important, as potential problems which can be created by guttering e.g. box gutters, should be avoided. Such gutters are known to overflow or split in time creating moisture problems, which apart from promoting mould growth also encourages insects. Regular maintenance and good housekeeping, as always, is of paramount importance.

It is also important to remove bird nests, which can harbour insects. Other insects such as bees and wasps, although themselves not a problem as regards the collections, their nests, when vacated are again a possible source of insects and they should be removed. They can also be a nuisance to visitors.

Housekeeping and sanitation

Most insects require only a small amount of water and food to survive, consequently the dust and moisture invariably found in buildings such as in store rooms, around plumbing etc., can be sufficient to feed insects once they are in the building. It is therefore essential that such sources of nutrition are kept to a minimum. As with the building structure, all crevices and cracks in interior fittings, around vents, ducts and piping etc., should be sealed. Prevent condensation forming on cold water pipes or tanks by the use of insulation. Regular inspection and good housekeeping which will remove dust, ensure leaking pipes are fixed quickly etc. will help to control possible problems.

It is obvious that food must be kept away from working, storage and exhibition areas. During construction, good building practice and supervision, plus informing workers why they should remove food scraps and building litter, could go a long way towards eliminating this food source for insects.

A new building may settle and move for a certain time period after construction is complete. Therefore, regular building inspection is important to monitor any movement, and then carry out remedial work such as sealing any cracks that may have occurred.

Fittings and structures within the building

It is one thing to prevent insects entering the building through the building fabric, but what about when insects have already entered, either through a missed crack in the building, brought in with an object and not properly inspected or treated, through an open door, or with a person or supplies entering the building? If insects are in the building it is necessary to prevent them moving freely about and also remove all sources of nutrition.

Within the building, storage units and exhibition cases should be designed with gaskets so that they close tightly. Take care with the choice of gasket material to ensure that chemicals harmful to the collections are not released (section 10). As mentioned earlier, sealing cracks and crevices of internal structures will remove breeding and hiding places for insects. The use of weather seals on interior doors, although looking a little unusual will also help in this regard. It is particularly important to have good seals between public areas such as exhibition rooms, sales areas, food services etc., and collection storage.

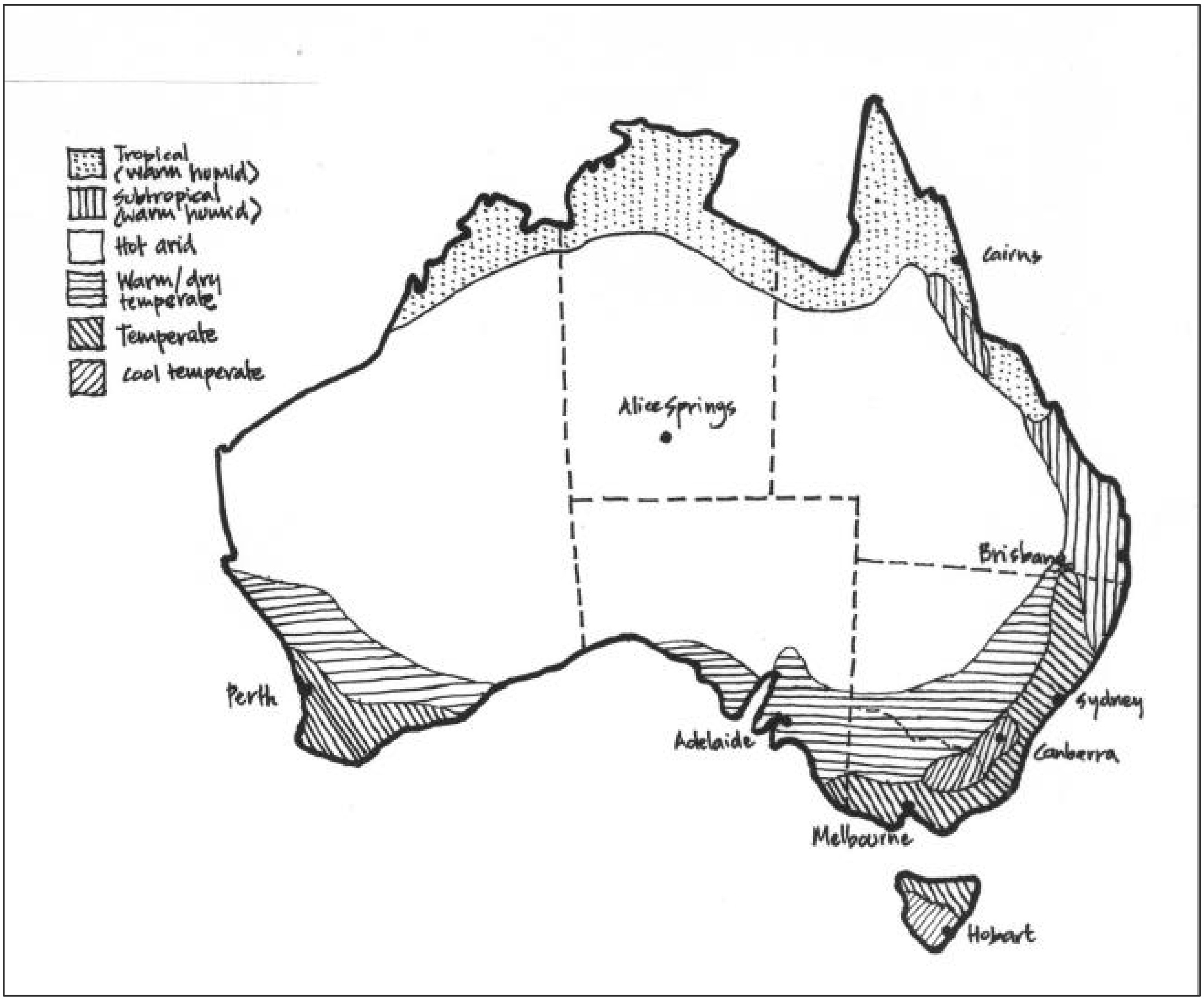
Good housekeeping, particularly vacuuming (requires high efficiency filter) is important. Dusting without vacuuming only moves dust, which can be an insect nutrient, from one area to another. The contents of a vacuum bag should be checked to determine whether any insects have been collected. These bags should be immediately disposed of outside the building. Putting them in an interior garbage bin is not sufficient as any insects collected may escape.

8. APPROPRIATE PASSIVE BUILDING STRATEGIES FOR DIFFERENT CLIMATES

8.1. Australia's climate zones

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) has established generalised climatic zones for Australia which are determined by the different design responses required in each area (Fig. 8.1.). These climatic zones are described below. They are useful in indicating the general design approach to be followed, but they cannot take account of local variations. The borders shown between the climatic zones are only indicative. The transition between one zone and another is usually gradual.

Fig. 8.1. Climatic zones in Australia



- ***Hot and dry:*** characterised by warm to mild winter days, cool to cold winter nights, very hot and dry summer days and warm to hot summer nights. This climate is prevalent in the centre of Australia, west to the coast and south to the Great Australian Bight.

- ***Tropical (hot and humid):*** characterised by very high humidity in the summer, or wet season, and high temperatures throughout the year, with cooler nights in the short winter, or dry season. This climate is prevalent along Australia's northern coast.

- ***Sub Tropical (warm and humid):*** characterised by mild to cool winter days, cool to cold winter nights, hot and humid summer days with slightly cooler nights. This climate is prevalent in coastal areas of New South Wales and Southern Queensland, and in the highlands of north-eastern Queensland.

- ***Warm dry temperate:*** characterised by mild to cold winter days, cold winter nights, very hot dry summer days and hot to mild summer nights. This climate is prevalent in the south-west of Western Australia, south eastern parts of South Australia, and the western slopes and plains of New South Wales and Victoria.

- ***Cool temperate:*** characterised by cold but often sunny winter days, cold winter nights, mild summer days with cool nights. This climate is prevalent in the highlands of the Great Dividing Range, in parts of Victoria, New South Wales, the ACT and in central and western Tasmania.

- ***Temperate:*** characterised by cool to cold winter days, cold winter nights, warm to hot summers with moderate to high humidity. This climate is prevalent in the south-east of Australia, the south west tip of Western Australia, and those areas of Tasmania that are not included in the cool temperate zone.

8.1.1. Hot and dry regions

The principal problems encountered in arid regions are excessive solar radiation, heat, low humidity, undesirable winds, wind-born dust and sand, and other air pollution.

Location and Siting. Following the principles outlined in section 7.1, the first line of protection is the use of appropriate siting. In urban settings, this would involve the close placement of buildings to afford mutual shading, especially on east and west, and the restriction of large open spaces. Compact building forms reduce external surfaces subject to solar loads, while courtyards and walled gardens increase the opportunity for the use of vegetation.

For new, freestanding buildings, locate them on lower slopes of hills to benefit from cooler air flow in the evenings. Retain cooler air with dams, barriers or shrubs. If possible, arrange the buildings as a compact cube, slightly elongated along the east-west axis, and built around a central courtyard.

Landscaping. Carefully selected planting can significantly reduce the environmental loads on the building.

Consider the strategy of traditional Islamic walled gardens: tall narrow leafed cypresses are used at the periphery to filter the dust and reduce wind speeds; cleaner, but still dry air is then humidified by a second screen of broad leafed trees. Pavilions in such a garden would be shaded by a large broad leafed tree such as a plane. One such tree might transpire as much as 500 litres of water a day; the extraction of the radiant and convective heat required to evaporate such a volume of water would typically represent a drop in temperature from say 57°C above the crown (such high temperatures result from the combined effect of air temperature and solar radiation) to 32°C in the shade, while humidity under the canopy might be raised by 30 per cent.

More radical use of plant material has been proposed and investigated. Measurements taken in the Gibson Desert in Western Australia, of a lightly clad building with a plant canopy of vines grown on a framework spaced from the walls and roof, showed net heat flow into the building to be uniform and virtually negligible. However, such a solution may not be suitable because of the problem of pest control.

If suitable water supply is available, provide for a pond or fountain as a source of natural evaporative cooling. Use lawns around the building to reduce thermal loads, but not against the walls of the museum buildings due to potential pest problems (section 7.2.3.3.). Car parks should be shaded, as should walkways and entrances to the museum.

Load control. The elimination of radiant solar load is paramount. Consideration should be given to lightweight shading superstructures, especially over the roof of a building. In any case roofs should be reflective colours, thermally massive and highly insulated.

Building construction. Conventional temperature control in buildings in hot arid regions relies primarily on the damping effect of massive construction. By careful design of exterior elements a lag exactly matched to the time difference between the incidence of greatest heat load and of lowest night temperature can be achieved. Similarly, massive internal walls absorb excess heat, and re-radiate it at cooler periods, on a daily cycle.

Walls

- Massive wall construction of mud or stone, or cavity brick or concrete to provide high thermal capacity walls will heat and cool slowly.

- Use overhangs, eaves and verandahs to provide protection from the sun

Floor

- Use solid concrete walls with deep foundations to provide a heat sink for the building.

- Isolate the walls, floor and pillars against rising damp.

Roof

- Massive roof construction of high thermal capacity is an advantage.

- Paint roof white to reflect thermal radiation.

- Keep roof clear from dust and debris which lower reflectivity.

- Consider earth cover on roof with irrigated ground covers, to reduce thermal load and actively cool by evaporation, but take care with water used on roof gardens and lawns.

- Don't locate ponds on roofs.

- If using a reliably waterproof roof, such as metal decking at sufficient slope, and if water supply is available, consider spraying the roof with water for evaporative cooling.

Windows

- Windows in perimeter walls should be small and recessed to prevent entry of direct sunlight.

- Locate windows on side of building away from the sun.

- Use overhangs, eaves, verandahs and trees to provide shade.

- Use external louvres or shutters of lightweight construction to keep out heat, light and dust.

- Use clear UV absorbing filters on the window glass; do not use heat reflecting or absorbing glass.

- More generous openings may be considered to internal courtyards.

Earth shelter. Where earth sheltered or underground construction can be safely undertaken without risk of flooding, the available thermal mass is even greater. Seasonal differences in temperature can be utilised. At six meters depth, undisturbed soil remains effectively at a steady temperature equal to the annual average temperature. Nearer the surface temperature swings are greater, but even with only 600mm cover, the temperature follows that of the monthly average temperature. If the soil surface is shaded and irrigated, such temperatures can be depressed by another 7°C.

Humidification. In deserts, humidification may be achieved by quite simple means. With no tradition in Australia of integrating water into the building design, it is difficult to offer Australian examples. But even modern examples may be readily found in other regions with such traditions. The Mohenjo-daro Museum, on the Indus in Pakistan, utilises massive brick walls set parallel to the prevailing winds, and a concrete double roof. A large pool of water is incorporated along the whole windward facade. Air passing over the pool is cooled, humidified and partially deposits sand and dust, before ventilating the museum halls. The Chandigarh Fine Arts museum in northern India employs similar passive humidification by being arranged around a courtyard with a large pool.

Better control over air flow, humidification and temperature may be achieved by more complex building forms, incorporating variations on the traditional wind catchers of Pakistan and Iran, and modern solar chimneys. At times of exceptionally low humidity, mopping the floors should be considered, as an effective way of providing a large evaporative surface.

The use of conventional evaporative coolers may be acceptable in most hot dry climates, but has the disadvantage of usually inducing larger temperature and humidity variations.

Light control. This should not rely on conventional window placement based on the practice of more temperate regions, having to be remedied by external or internal shading devices. Relatively small external openings should be strategically located for complete sun control, and to provide a combination of reflected light to floor, wall and ceiling surfaces. Where planted courts can be established, visual relief for the interior should be provided by outlook into the vegetation. The Japanese practice of placing openings low in the wall directs gaze downwards to a relatively small area, which can be highly landscaped and well maintained, perhaps inside a boundary wall. Thus contrast between the low internal light level external illumination is reduced, and glare eliminated.

8.1.2. Hot and humid regions

Design of museums, keeping places, archives and other repositories in the warm humid tropics will almost inevitably involve accepting higher temperature targets or set-points.

If, after consideration of the collection and visitor usage patterns, considerably higher than conventional temperatures are considered acceptable, design strategies will favour relatively closed, thermally massive buildings with some night ventilation the elevated temperatures being used to control relative humidity in enclosed spaces.

On the other hand, if lower temperatures, comfort ventilation, and air movement for mould control are considered priorities, lightweight, elevated construction similar to traditional housing is likely to be preferable. In this case, control of air-borne pollution will generally become a critical issue in the design and management of the museum.

Location and Siting. The priority of reducing environmental loads applies equally in the hot humid tropics. However, the implications for siting and building are different. Buildings will be generally more widely spaced, reflecting the relative ease of maintaining shade on intervening open areas by fast growing planting, and the need to encourage access to breezes for naturally ventilated buildings.

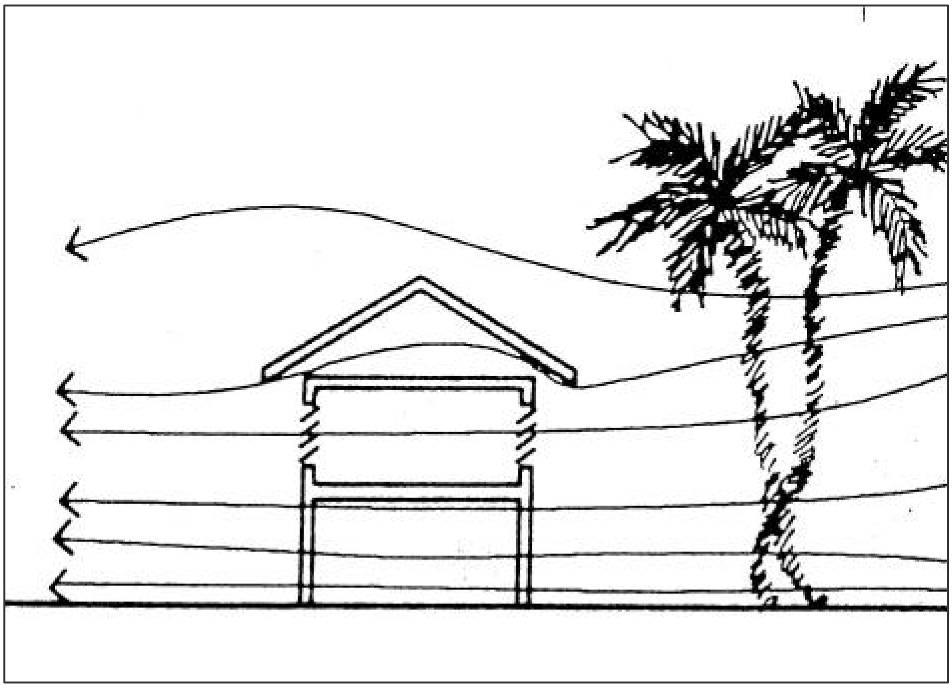
Build on the top of or the windward side of a hill, preferably on a north or south facing slope. If possible, site the museum away from sources of air pollution, eg. from industry and motor vehicles; on affected sites, utilise planting to reduce exposure.

Landscaping. Use trees and shrubs to provide shade for the building and car parks; the species will depend on the type and height of shade required. Car parks should be sealed if possible to rapidly shed water and dry in the sun, reducing the moisture level of the air. Keep sources of water away from the building. Use lawns to reduce thermal load on the building. Don’t plant vegetation close to, or on the building, as they attract insects and rodents, and harbour air pollutants (section 7.2.3.3.).

For unfavourably oriented buildings, vegetation-covered frames or walls to provide barriers can be used to change the exposure to ventilating breezes.

Building shape. Individual buildings may be more elongated, with their long axis east to west. This is a simple function of the ability to use roof overhangs to control overhead sun, which may come from either north or south, while the low rising and setting sun is more difficult to avoid. 'Shallow' building plans can also facilitate cross ventilation by prevailing breezes (Fig. 8.2.).

Fig. 8.2. Well spaced houses oriented on E-W axis, with narrow plans, encourage good cross-ventilation



Natural ventilation. If it is decided to deal with elevated humidity only by the traditional technique of encouraging natural ventilation, it will dictate planning, form and construction of the building.

There are two ways of inducing natural ventilation:

- Cross-ventilation due to differences in pressure on the windward and leeward sides of a building. This requires appropriate placement of operable openings, to serve as inlets and outlets (see also section 7.1.2.4.).

- So-called ‘stack effect’, which relies on the buoyancy of heated air, rising in a tall space and allowed to escape at a high point in the building, to be replaced by air drawn in at low levels.

Both control of mould, and the enhanced comfort of staff and visitors depend on certain minimum air velocities. Stack effects, while they are useful for air exchange, and therefore temperature control, simply do not produce such velocities. Ventilation under such circumstances can only be assured by encouraging available breezes, and building designs that encourage good cross ventilation.

Building plans must therefore be such that cross ventilation is not obstructed by internal partitioning. Orientation is not as critical as one might think, as planting and other external elements can be used to modify the distributions of high and low air pressures around the building. The placement of openings in the building fabric, on the other hand, is critical. To enhance the velocity of a light breeze, outlet openings must be larger in area than inlet openings, which in turn must be so located as to direct the air stream onto occupants and the stored objects.

Driving rain. Control over the permanent ventilation openings will become the major design parameter. Where buildings are orientated perpendicular to the direction of the prevailing wind for natural ventilation, openings are vulnerable to driving rain. Water finds a way through the smallest opening and the wind can force it up a vertical surface. Even with deep roof overhangs, penetration of water through openings designed for ventilation may be difficult to avoid. It would be best if the solution is in planning, rather than construction - areas on the periphery of the building may be dedicated to circulation spaces with finishes designed to cope with intermittent wetting. Storm shutters may be required for some extreme situations.

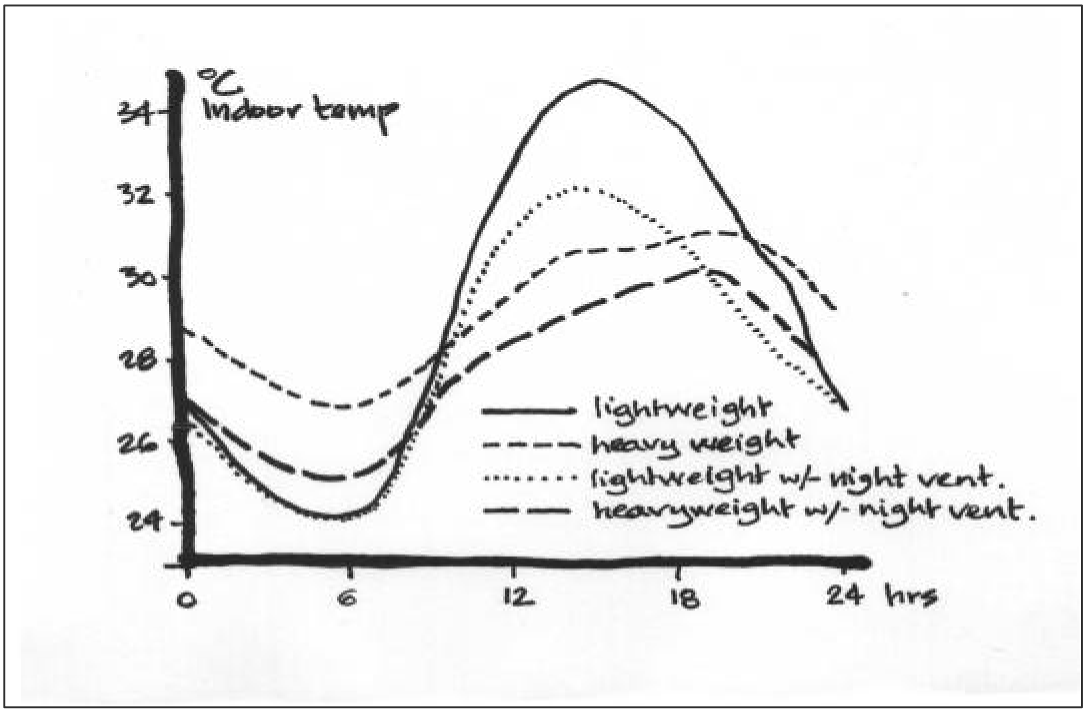
Openings and sun screening. Openings for light generally do not need to be as restricted as in the hot arid zone. Since the 1960s it has been popular in tropical climates to build grids, or screens, of in-situ concrete or specially designed perforated concrete blocks, to fully sun-screen the facades of larger buildings. These grids and screens are often referred to as ‘brise-soleil’ after the name given to them by Le Corbusier, the architect who was so influential in popularising this approach. However, it is better not to rely on screening conventional openings from the sun by the use of such 'brise-soleil' type grids, because they act to store the solar radiation and effectively transfer it to ventilating air passing over them on the way to the interior. If the screen is structurally connected to the building, heat will also be passed to the interior by conduction.

Thermal mass. As long as solar gain is minimised, with permanent ventilation for air movement, the thermal environment of the building will follow that of the outside closely, almost regardless of the materials of construction.

However, even with the smaller diurnal temperature swings of 5 - 10°C in a hot humid climate, the storage effect of structural mass is just about worth considering. This is particularly the case where the building is unoccupied at night as a museum typically might be since the usual criterion of rapid cooling to improve sleeping conditions does not apply.

When designing a building to give high air movement, one anticipates ventilation rates in excess of 50 air changes per hour (ac/h). This means that internal gains would be ventilated away quickly. With a reduced ventilation rate in the daytime, the building will be much more sensitive to internal gains of any kind, and much more care must be taken with shading and insulation, etc. The effects of the weight of building materials on damping the external temperature, with and without venting, is shown in Fig. 8.3.

Fig. 8.3. Result of night simulations for a building in Darwin



Furthermore, restricting daytime ventilation rate to 1ac/h, all physiological cooling effect for occupants, and any role in prevention of mould due to natural air movement will be lost. This air movement would have to be provided mechanically, typically by overhead fans. Alternatively, this approach could be suitable for a museum store, with very low occupancy levels.

Dehumidification. Where air exchange with the outside is restricted, consideration may be given to dehumidification, either by mechanical, or by 'passive' means.

Passive dehumidification at the scale of whole buildings is normally considered very difficult, because of the amounts of desiccants required to deal with the large air quantities. The more usual approach is to use a dedicated refrigerative dehumidifier. However, it should not be forgotten that a conventional wall mounted or split system air conditioner does condense water vapour on its cooling coils. Under many circumstances, it may be demonstrated that such air conditioners, with no humidistat control but set to recirculate internal air, will achieve comparable dehumidification with the additional benefit of providing some cooling. The advantage of using domestic air conditioners is the comparative ease of maintenance and service, compared to dedicated dehumidifiers.

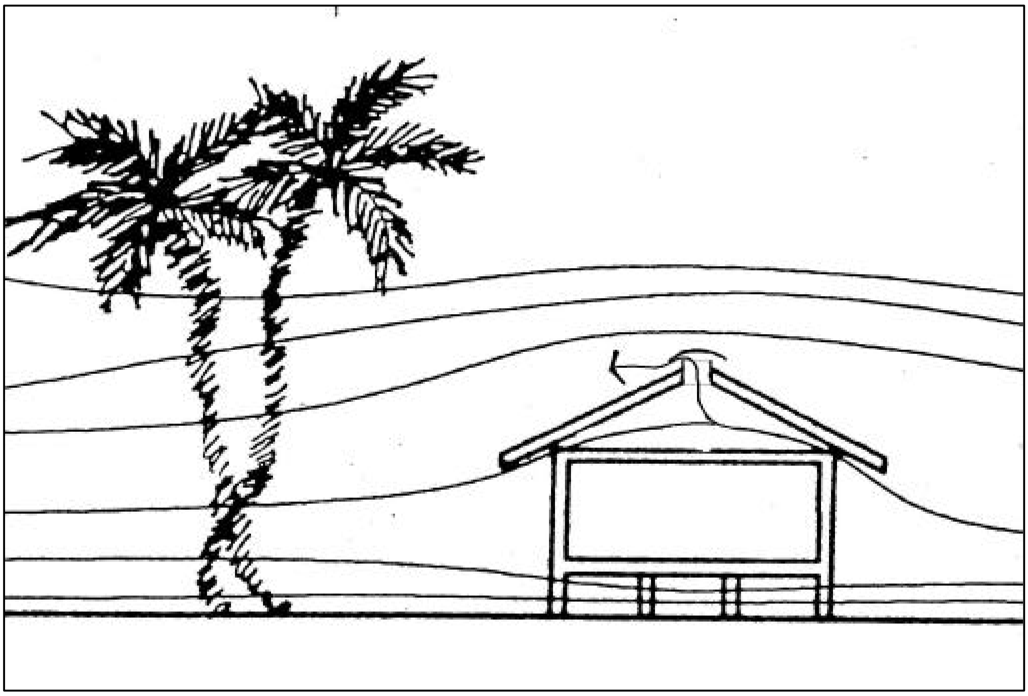
Indirect evaporative cooling. Despite high ambient RH, some limited potential for evaporative cooling does exist. However, to be utilised, such evaporative cooling has to be 'indirect'. In simple terms, the cooled but saturated air which is produced by a conventional evaporative cooler, must be passed through a heat exchanger to cool another separate stream of air without adding moisture to it. The use of such units only becomes relevant in conjunction with dehumidification, since the RH of the interior air still rises as its temperature drops. It is doubtful that any presently available system offers a significant advantage in energy costs, or in reliability, over refrigerative air-conditioning.

A specialised form of indirect evaporative cooling which may be useful where there is a plentiful supply of water, is spraying of the roof by means of simple sprinklers. Surface temperature of roofing is reduced from over 45°C to typically 28°C.

Roofs in the hot-humid zones must be designed to shed rain quickly, and will most often be relatively steeply sloping. For maximum rejection of solar radiation, use white, or light colours.

Being the major source of radiant solar load, consideration should be given to ventilated double roofs (Fig. 8.4.). The use of light metal roof as external sheeting in this case is problematic, as the drumming noise from frequent rain can exceed 70dBA and can compromise activities in the building. In normal single roof applications, thermal insulation would be placed in contact with the external sheeting to dampen this noise. But in double skin roofs, the insulation would be wasting its potential for heat reduction in this location. Therefore a rigid, massive external roof finish, such as tiles, may be more appropriate for noise control. The permanent ventilation of the roof cavity can be assured by correctly designed ridge ventilators. Additional extract ventilation may be used to exhaust some of the warm air from under the ceiling, as well.

Fig. 8.4. Eave and ridge vents allow cooling of attics



8.1.3. Cool temperate regions

Australia has no true cold climates. Even the alpine regions do not experience winter temperatures comparable to much of continental Europe or North America. Building strategies in cool temperate regions such as the Australian Capital Territory, New England, the Victorian Highlands, and much of Tasmania, need to balance dealing with winter cold, while also protecting collections and achieving human comfort during warm to hot summers.

By definition cold winters need additional heat input; therefore the best strategy is to conserve heat. But because of the availability of relatively high amounts of winter solar radiation, buildings should also exploit passive solar design principles.

Passive solar design of museums is particularly problematic, because of the damaging effects of sunlight on most museum artefacts. The appropriate use of solar heating in this specialised application is briefly discussed below.

Location, siting and landscape. South facing slopes will significantly reduce available solar radiation, and ground surface temperatures may be reduced enough to maintain frost cover long into winter days. Slopes facing up to 40° west of north would be beneficial in winter, but severely aggravate summer sun exposure. Overall, north facing slopes, up to 20° east, are considered optimal. Shelter from both cold winter winds and hot summer winds is generally required. As prevailing wind directions in the two seasons differ, shelter planting should be carefully investigated. At entrances, external wind protection is especially important. Planting should assure sun access in winter, to north elevations of buildings. Ideally, trees close to buildings would be deciduous, admitting winter sun and providing summer shade and evaporative cooling.

Building shape and orientation. Reduced surface/volume ratio of the building to minimise potential heat losses has to be balanced against optimum planning for passive solar design. A rectangular compact plan of approximately 1.5 2:1 ratio is desirable, with the long axis oriented east-west. Two storey designs improve the isolation of interior spaces from the external environment. Generally entrance and exit from the building should be by way of airlocks.

External envelope. In order to reduce winter losses and summer heat gains, insulate the building envelope to high standards. Windows should be moderate in size, and double glazing will usually be justified on other than the northern orientation. Construction should be air-tight, compatible with the requirements for minimum ventilation. External doors and windows should be weather striped. Consideration should be given to simple heat exchangers to retrieve heat from exhaust air, in order to preheat incoming air.

Building mass. Though the building may not be continuously occupied, environmental conditions are expected to be maintained on a continuous, rather than intermittent basis.

Therefore, there is an advantage in having an appropriate amount of internal thermal mass, to reduce the internal temperature swing to a minimum. A winter temperature swing of less than 4°C without supplementary heating should be considered an appropriate standard for the construction.

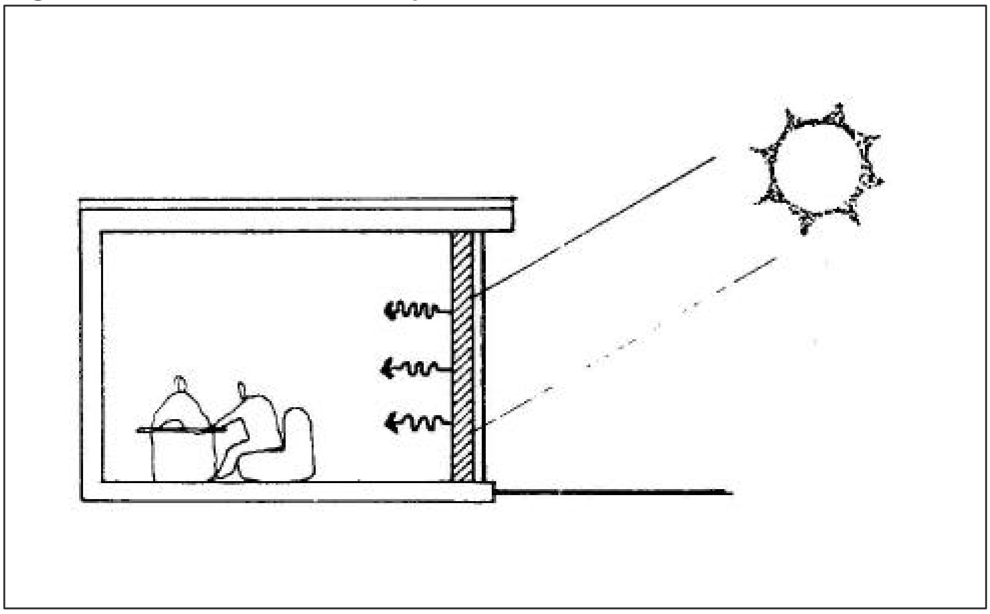
Thermal mass is a necessary component of passive solar design. It absorbs excess heat during the sunlit period, and returns it to the space at night. For maximum effectiveness, thermally massive elements should have a large surface area, and a thickness based on their optimum diurnal heat capacity.

Thermal mass is also beneficial during the summer. During the day, it takes up heat from the interior, moderating any temperature rise. During the night, it can give up its stored heat to controlled ventilation.

Passive solar design. Where good winter sun is available, glazing should face the equator, with insulated shutters for control of conducted heat losses at night. However, except for areas separate from display and storage, conventional 'direct gain' solar collection is unacceptable. Alternative systems include:

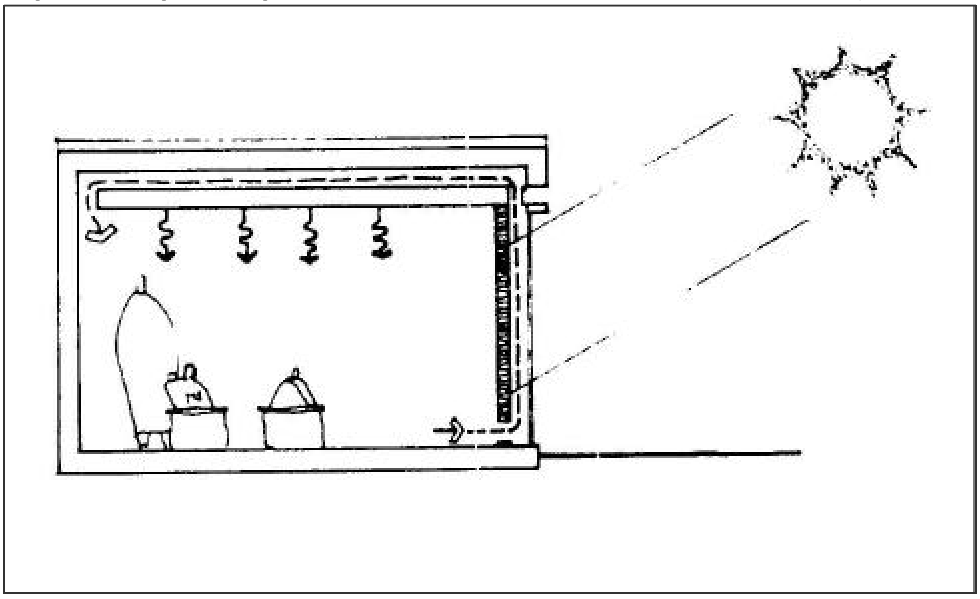
- Thermally massive collector walls, such as the *Trombe* wall (Fig. 8.5.). The material and thickness of the wall may be adjusted to achieve the desired time lag, in order to provide the majority of heating during the evening and night periods.

Fig. 8.5. The *Trombe Michel* system



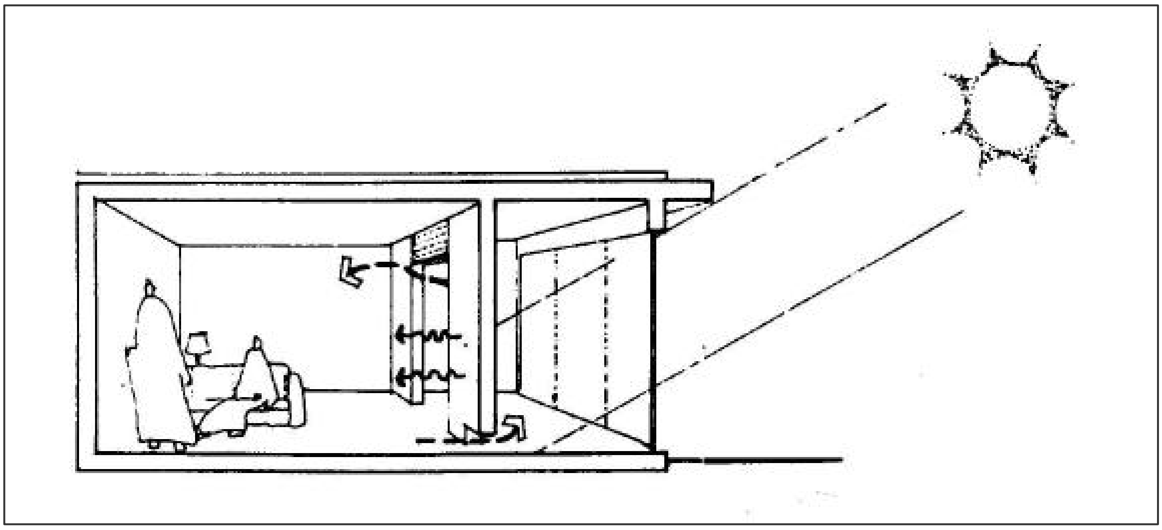
- Light-weight collectors generating overheated air, such as the *Barra-Constantini* collector wall (Fig. 8.6.). Heated air supplied by the collector is usually supplied to spaces remote from the sunward facade, by natural convection, or small 'parasitic' fans. If warmed air is routed through spaces in a thermally massive structure, some delayed heating at night is also achieved.

Fig. 8.6. Light-weight collection panel: the *Barra-Constantini* system



- Attached sun spaces. Such spaces may be of quite varied configuration. Typically, they would accommodate ancillary functions such as circulation, or even a cafe in a larger institution. They work on the basis that they 'over-heat' during sunny weather, and cool below acceptable limits at unoccupied periods. Even during such periods, they still represent an intermediate environment between the interior and the exterior, thus reducing heat losses in winter. Passage of heat from the sun space to the display or storage spaces may be by way of a thermally massive wall with a calculated time lag, a lightweight insulated wall, or natural or assisted convection of air. Attached sun spaces must be carefully shaded and well ventilated during the summer months (Fig. 8.7.).

Fig. 8.7. Attached sun space with mass wall and ventilation openings



In each of the above systems, direct sun penetration in the heated space is completely avoided.

8.1.4. <u>Temperate regions</u>

Most design principles described for cool temperate climates apply.

Winter requirements are similar to cool temperate climates, but because the under-heated period is not as severe, surface/volume and insulation standards are not as a rigorous. Solar heat input in winter is desirable, so orientation and other considerations are the same as for cool temperate.

As overheating in summer is possible, structural sun control is necessary. Cut-offs between winter heating and summer sun exclusion depend on average monthly temperatures. Consider the use of deciduous vegetation for automatic shading discrimination between winter and summer.

As night temperatures are often below appropriate, even in summer, thermal mass is desirable. The thermal mass is, of course, also beneficial for passive solar design for winter. Summers are generally more benign, with lower maxima and less frequent extreme days. Ventilation can cope with most summer overheating by removing the surplus heat. But if shading is adequate, such overheating should rarely occur. However, on a few extreme days, severe overheating may combine with elevated humidities to produce conditions worse than those in the tropics. On such days, additional care needs to be taken with reducing solar gain and air exchange rates, to limit the extent of internal temperature and humidity rises.

9. MATERIALS SELECTION FOR DURABILITY

Museum curators, conservators and managers are rightly concerned with the preservation of museum objects. However, often not much attention is paid to the durability of the museum fabric. The degradation of the fabric may affect the operation of the museum in a number of ways including:

- necessitating costly repairs;
- breakdown in the function of the building, including leaking roofs; and
- degrading materials can give off organic or inorganic contaminants, which then affect the air quality of the museum.

For these reasons it is useful for museum staff to have a basic understanding of materials degradation and its relation to building design and climate.

9.1. Basic Mechanisms of Degradation

In Table 9.1. the most common degradation mechanisms affecting common building materials are given, as well as the susceptibility to various degradation agents. It is necessary to differentiate the mechanisms on the basis of location (inside or outside the building), as materials will be exposed to different degradation patterns depending on the extent of exposure.

Table 9.1. Degradation mechanisms and environmental factors.

Material	Position	Degradation mechanism	Environmental Factors							
			Tempe rature	Salt	Condensa tion	RH	Wetness	Biologica l agents	Pollution	UV
Metal	Exterior cladding	Corrosion	Moder ate	Strong	moderate	Strong	Strong	None	Strong	Low
Coated metal	Exterior cladding	Corrosion	Strong	Strong	Moderate	Strong	Strong	None	Strong	Strong
Bricks	Exterior cladding	Weathering/salt attack	Weak	Strong	Moderate	Strong	Strong	Low	Moderate	Low
Concrete	Exterior cladding	Salt attack, freeze/thaw, AAR	Weak	Strong	Weak	Weak	Strong	None	Strong	Low
Tiles	Roof cladding	Salt attack/ fungal growth	Weak	Strong	Weak	Weak	Moderate	Moderate	Strong	Weak
Stone	Exterior cladding	Salt attack/ chemical dissolution	Weak	Strong	Weak	Weak	Moderate	Moderate	Strong	Weak
Adhesives	Exterior cladding	Water penetration, photo-oxidative degradation	Strong	Weak	Moderate	Strong	Strong	None	Moderate	UV
Glass	Exterior cladding		Strong	Weak	Weak	Weak	Weak	None	Moderate	Moderate
Timber	Exterior	Termites/ fungal attack corrosion of fasteners	Low	Low	Low	Moderate	Strong	Strong	Low	Moderate
Paint	Exterior	Chalking	Low	Low	Moderate	High	Moderate	Low	Low	High
Plastic	Exterior	Photo-oxidation	Strong	Weak	Weak	Weak	Moderate		Strong	Strong
Polyester-resins	Exterior	Yellowing	Strong	Low	Low	Low	Strong	None	None	Strong
Metal	Building envelope	Corrosion	Weak	Moderate	Strong	Moderate	Strong		Moderate	None
Timber composites	Building envelope	Hydrolysis of adhesive - internal bond failure	Strong	None	Low	Strong	Strong	Low	Low	Low
Timber	Building envelope	Termites/ fungal attack corrosion of fasteners	Low	Low	Moderate	Moderate	Strong	Strong	Low	Low

The degradation of some individual groups of materials is described below.

9.1.1. Plastics

Plastics must resist photo-oxidation, moisture effects and temperature ageing. Photo-oxidation is primarily promoted by UV irradiance. However, temperature and relative humidity (ie. higher degradation at higher temperature and RH) also influence the rate of degradation. The greatest hazard for polymer degradation occurs across all northern and tropical Australia with a particular hazard in the north west region of the country.

9.1.2. Metals and metal components

The life span of metals is limited by corrosion that is controlled primarily by pollutant level (including sea salt) and time of wetness for bare and metallic coated components. The same, plus UV irradiance applies for metals coated with a paint system. The highest hazard levels are found in the southern part of the continent where relatively high relative humidities (RH) occur combined with significant salt production by the southern ocean and distributed across southern Western Australia, parts of south Australia, Victoria and Tasmania by prevailing westerly winds. The hazard for painted metal is a combination of the UV hazard and corrosion hazard. It is also necessary to take into account a local hazard, in particular, industrial activity or sources of airborne salinity (e.g. surf beaches).

9.1.3. Masonry

The most common form of deterioration of masonry units (bricks) and mortar beds is salt attack, although they may be susceptible to freeze/thaw attack in cold climates (highland areas in southern Australia) and to erosion. Under severe conditions, prolonged wetness and wet/dry cycles may also promote deterioration by assisting salt attack. Masonry units are also subject to moisture-induced expansion and efflorescence. The former may promote cracking and the latter decrease the aesthetics of the structure.

9.1.4. Concrete

Concrete may suffer from alkali-aggregate reactions and freeze/thaw effects. Iron reinforcement in concrete may corrode with the rate of corrosion being controlled by state of carbonation, oxygen availability, wetness and presence of salts and pollutants.

9.1.5. Timber

Any timber component in a house structural, architectural, cabinets and furniture, may be subject to insect attack (termites, lyctids and furniture beetles section 3.5) and fungal attack (section 3.2). Timber in exposed situations may also be subjected to weathering, chemical degradation or deterioration around corroding metal.

Timber types are assigned a ‘Natural Durability’ rating which refers to the durability of the heartwood of the timber with respect to resistance to decay and termite attack in an in-ground location. Class 1 timbers are highly durable and include grey ironbark, forest red gum and Cypress pine, while Class 2 or durable timbers include jarrah, spotted gum and blackbutt. Class 3 timbers are moderately durable and include messmate and rose gum whilst Class 4 timbers are non-durable and include Radiata pine, Douglas fir and slash pine.

9.2. Environment classification for durability

Durability scientists refer to macro, local and microclimates. The macro is on the scale of a climate zone (e.g. tropical or sub-tropical), local being the immediate few streets around a building, and micro being actually adjacent to the components.

Some local effects such as the severe marine, marine, severe industrial and industrial environments are defined in Australian Standards. Other local effects are less well defined. Local effects predominantly influence climate and wind patterns. Wind in turn may carry rain (wind driven rain), human made pollutants (sulphur oxides, nitrogen oxides) and natural aerosols (sea salt/dust etc) and pollutants. Local effects can cause significant variations in degradation between buildings located in relatively close proximity. For example, it is well established that the corrosion rate adjacent to surf beaches is very high due to the corrosive effect of marine aerosol. Breaking waves give rise to a fine salt rich aerosol, which is then carried by winds across the land. On clear flat land it is found that airborne salinity decreases in an exponential manner with distance from the coast.

However, it has been observed that in urban areas or in forests the airborne salinity below the roof top of houses or canopy of trees is much lower than in the case of open terrain. Furthermore, rather than the salinity decreasing in an exponential manner, its decease is abrupt at the first few layers of houses or trees. What in fact happens is that the aerosol is deposited on the obstacles and then depleted to the height of the obstacles. Aerosol from above this height gradually settles down but this is a slow process. This effect thus leads to very high corrosion rates on houses facing surf beaches and surprisingly low corrosion rates for houses (in built up areas) behind the first two or three rows of houses. This effect also occurs for dust particles. If a cultural building is positioned in a zone where there is likely to be significant airborne matter the impact on the building can be reduced by planting trees or building other barriers to trap such matter.

The environment can be altered on the micro-level even more than on the local. Some of the ways the micro-environment can alter the magnitude of the degradation parameters are defined below:

- *Shading* In the context of material durability, shading of external walls is important to reduce heating of walls. The additional heating effect of direct sun on a dark vertical surface may be 20°C or more, in comparison to the ambient air temperature. It is also important in order to reduce the effect of wind driven rain. Shading to reduce the effect of UV follows the same principles as that to reduce the heating of sunlight.

- *Airflow* External flow patterns are important in that they can channel wind driven rain, pollutants and particles onto the building facade. Use of barriers as discussed above can reduce these effects. The deposition of air transported species on a facade is rarely uniform, rather deposition commonly occurs where the building form promotes an abrupt change in air speed or direction. Airflow within the building envelope is also vital. The building functions as a whole and often air from the sub-floor may flow up the wall cavities into the roof space. This can be beneficial in terms of reducing temperature and humidity variations, although in some circumstances, it may promote condensation.

- *Ventilation* The role of ventilation is complex with regard to microclimate and durability. Ventilation into spaces with a moisture source can be extremely beneficial as it exchanges the relatively dry external air for the moist building space air. This is particularly the case for sub-floors where moist soil provides a continuous moisture source, and ventilation is mandated to control sub-floor conditions. On the other hand, ventilation can sometimes raise the RH if the building space is at a lower RH, or it can promote condensation if significant temperature gradients exist.

- *Condensation* It can occur when there are significant temperature or humidity gradients across the building fabric.

- *Soil moisture/drainage* As described above, a classic example of a moisture source in poorly ventilated building spaces, is a sub-floor above moist soil. A number of actions can be taken, including ensuring good ventilation, ensuring that there is good drainage away from the sub-floor or providing a vapour barrier on the soil to prevent moisture entering the sub-floor.

- *Building practice* Unfortunately, the microclimate in a building is often the result of bad practice, absence or failure of damp courses or water-proof membranes, etc.

- *Solar effects* Radiative heating and cooling may have pronounced effects on the microclimate. The classic example is the metal roof which reaches high temperatures during the day as it absorbs radiative energy, but then radiates heat during cloudless nights to cool well below ambient. As well as exaggerated mechanical movements in the material and its fixage, the conditions underneath the roof sheeting show a very wide variation in both RH and temperature, with condensation on the underside of the sheeting being common.

- *Food sources* It is well established that termites are more prevalent in buildings where there are external food sources for the termites. Such food sources may include dead trees, unprotected cut timber etc.

Having analysed the environment that a component is subjected to, the challenge is to select a material that is suitable for that environment.

There are a number of standards and guidance documents that give materials a resistance rating which is then matched to the hazard level of the environment, or alternatively give a list of suitable materials for a given environment hazard.

10. ENVIRONMENTAL CONTROL OF DISPLAY CASES AND STORAGE AREAS

If it is possible to control the museum environment at the building or room level, then conditioning of display areas and cases, and of storage areas is not critical. However, as will be more common in most museums, it may not be possible to achieve adequate control of T, RH and air pollution in particular, and therefore it is necessary to use display cases and storage rooms and containers as a secondary level of environmental control (see also section 7.1.3.). Objects which are on open display in the museum, will obviously be subject to effects of the environment, however, it is possible to provide better control for objects which can be enclosed.

10.1. Control of display cases

Similar to the proposals for providing a stable environment for a museum building using passive means, it is necessary to control the T, RH, illumination and UV levels, air pollutants and pests inside a display case. However, the first step is to determine the type of display case, in particular the materials of construction and how air tight it is. Due to problems of availability of materials and quality control in constructing display cases for museums, it must be assumed that display cases will be somewhat ‘leaky’, and therefore the following advice concentrates on leaky display cases rather than perfectly sealed ones.

10.1.1. T and RH

The location of display cases within the museum is important. If these are free standing then air in the room will tend to provide a first level of environmental control, which will be made even more stable by the fact that the case is closed. However, if cases are against walls, then care is required as the cases may be heated or cooled depending on the solar gain of the wall. Changes in temperature of the wall will be conducted to the case causing corresponding changes in RH. If on a wall away from the sun, it could be cool enough to increase the RH behind or inside the rear wall of the case causing condensation, and increasing the potential for mould growth. For such cases an air gap or insulation is necessary to avoid these problems.

If there are large air gaps in the display case then the internal T and RH will be similar to the levels in the room. If these are acceptable then no further control of the case environment is required. If control is required, then the first step is to make the case as air tight as possible, using inert silicone sealant materials to seal the gaps. Do not use rubber seals (section 3.4. and 9.1.1.).

The RH changes in the ‘sealed’ case will be determined to a large extent by the local temperature changes. This means that direct sunlight must never be allowed to fall on a case, and any artificial illumination must be external and far enough away not to heat up the contents of the case. A stable temperature will ensure a stable RH, and even if this is too high, or too low, it can be controlled locally.

This is possible with the use of buffering materials which act in a similar fashion to organic materials. As discussed in section 7.1.2.5. (on RH control), organic materials take in moisture as the RH increases and release moisture as the RH decreases, levelling out the RH fluctuations. Instead of using the objects inside the case to provide this buffering effect - as if too severe it may damage the object in the process of buffering the RH, materials such as silica gel and activated charcoal are now commonly used in museums. Both work by adsorption, and adsorb and desorb moisture in opposition to changes in RH. Whereas silica gel can only adsorb water, activated charcoal has the added benefit of being able to remove air pollutants such as the oxidising gases of sulphur and nitrogen oxides, and ozone (section 7.2.1.).

Silica gel is not only a desiccant, but can be conditioned to a set RH by holding it at this RH for as long as possible, at least two weeks. It has been found from theory and practice, that about 20kg of conditioned silica gel will be required to control the RH inside a display case of one cubic metre capacity, but this does require the case to be sealed. A leaky case will require much more silica gel, and therefore if too leaky the use of silica gel may be a waste of time. There are more efficient forms of moisture control based on silica gel such as ‘Artsorb’ and ‘Arten Gel’.

If silica gel is used to control the RH inside a display case then continuous or at least regular monitoring of the case environment is required to determine if the RH is being controlled effectively. No sorbing material is 100 per cent efficient as it takes in and releases moisture, and after time (depending on the rate and magnitude of the RH fluctuations), the silica gel will need to be reconditioned. Display cases will have to be specially designed to accommodate the silica gel, normally as a tray or drawer built into the bottom of the case which is easy to remove for reconditioning. The trays or access ports will also require good seals. The silica gel which comes in the form of granules, should be laid out as thinly as possible and not more than 2-3cm deep. ‘Artsorb’ is also available in the form of cartridges and felt, which can be placed within the case.

The RH can also be buffered by the use of organic materials, in particular cotton. Such materials must be stable, eg using undyed cotton which has not been treated with chemicals such as fire retardants which, can release harmful vapours within the case.

A traditional means of controlling mould growth in cupboards in tropical countries is to use a low intensity heat source, such as a low wattage incandescent light bulb. This is located at the bottom of the case (or cupboard) and the increase in temperature from the bulb lowers the RH sufficiently so that mould growth does not occur. This heat source also produces air movement by convection which is useful in preventing mould growth. If this system is used in a display case then it must be vented to allow air flow through the case. Care must also be taken that the increase in air temperature does not cause other problems. Although a common practice in storage cupboards for clothes it is not widely used in museums.

10.1.2. Light

As discussed in section 3.3. it is necessary to control both the illumination (lux) and UV radiation (µwatt/m^2) levels in the museum gallery and also that falling on the displays in cases. The recommended levels of illumination and UV (section 4.2.) will apply, as will their methods of control. Remember in general, incandescent lights produce heat but low levels of UV, whereas fluorescent lights are cool but unless covered by perspex diffusers, give out high levels of UV.

It is preferable to have any light source outside the display case, as if inside it can cause a rise in temperature, and corresponding fall in RH when the light is switched on and off. This of course depends on the type of light source with incandescent producing more heat than fluorescent. Other problems using internal light sources are that it becomes more difficult to filter out UV radiation, and also to use the inverse square law to reduce illumination levels doubling the distance will quarter the illumination level. Note also, some insects are attracted to light, and many display cases can be seen containing the remains of dead insects. This is unsightly and requires cleaning, but more important the insects may have damaged the objects in the case. However, there are occasions where internal illumination of objects is required, and careful selection and design of the lighting system is necessary to produce the best effect but reduce risk of damage to the objects on display. For example, any lights should be at the top of the case with upright cases and at the side and top for table cases. The cases must also be vented to enable any heat build up to escape but screens must be in place to prevent entrance of pests.

With the use of clear UV absorbing filters it is possible to reduce the levels of UV at the display case level. If these are incorporated into the design of the case by using laminated glass containing a UV filter, or applying the UV filter to the glass, then UV levels can be controlled to the accepted levels. It is very difficult to achieve the same effect with illumination levels and heat from light sources, as the required filters will either alter the colour temperature within the case or darken the case. These factors should be controlled outside the case.

10.1.3. Air pollutants

Within a display case it is necessary to remove the air pollutants which come into the building and any pollutants produced by the materials of construction of the display case. With a well sealed case, the exterior pollutants should not be a problem, and materials of construction should be chosen or well sealed so as not to release harmful organic vapours. For leaky cases the air pollution problem can arise from both inside and outside the case.

Control of air pollutants in display cases may be achieved by one or all of:

(a) minimising access of air pollutants to display case interior by constructing a tightly-sealed unit;

(b) constructing the display case with low- or non-pollutant emitting materials (section 10.3.); and

(c) air cleaning of the interior of display case.

Experiments with a display case that was not tightly sealed showed that removal of pollutants with sorbents present was typically one order of magnitude faster than without sorbent. However, in general it is expected that the level of reduction by passive sorbents will depend on the relative levels of ventilation and surface area of sorbent presented to the display case interior.

Activated carbon (or charcoal) powder is the favoured absorber for pollutants. It is placed in a shallow tray or purchased in the form of cartridges or as fabric which can be used to line the interior of the case.

If wood or wood products (e.g. fibreboard) have to be used for constructing display cases, then from recent research there are procedures which can be carried out to lessen the emission of harmful gases which are normally formaldehyde, acetaldehyde, acetic and formic acids. It is necessary to seal the wood and prevent the organic gases from escaping into the atmosphere, and the best materials are barrier foils such as plastic or aluminium, which have to be applied to the wood surface and well sealed. However, as activated charcoal filters and barrier foils may be difficult to obtain in some places, then coating systems are a second alternative (section 7.2.1.2.). Here research has shown that the best coating systems are polyurethane lacquers, with varnishes and water-based systems not being very effective. It should also be noted that ventilation of the case can make some difference to the concentration of organic gases inside, but by itself is not sufficient to provide a pollution-free environment.

10.1.4. Pests

Pest control is much easier at the display case level compared with controlling a room or building. If cases are well sealed then few insects will enter, however, even with just a few minor cracks insects may get in, remembering that the case will be illuminated, even if from outside, which will attract some insects. Integrated Pest Management is required to control pests (section 7.2.3.1.), and if there is concern about insects then precautions are necessary, using baits and traps around the base of the case or inside the case, and placing insect screens over any gaps, noting that it is impossible to seal cases with sliding doors.

The problems of mould growth will be controlled if the RH is controlled (section 7.2.2.), and it is unlikely that large pests such as rats and mice will get into display cases as these should be excluded at the building or room level.

10.2. Control of storage areas

Storage rooms are probably the most important area of the museum, as the majority of museum objects spend most of their life in storage. In addition, objects may lie in storage for years without being inspected, which means that if they are in an adverse environment or attacked by insects, there can be serious damage occurring to the objects which is not observed until too late. It is, therefore, essential that storage areas provide a stable environment at appropriate levels of T and RH, free from air pollutants and pests.

If store rooms are only used for storage purposes (they should not be used as work areas), then staff enter infrequently and for a short time, so there should be little load on the environment from the presence of people and the use of lights. A few buildings in temperate climates have been especially constructed to provide passive environmental control for the contents, usually a library or archive, but as yet there have been few specifications for repositories for tropical climates.

As different materials, particularly organic and inorganic, prefer different levels of T and RH for long term preservation (section 4.1.), if possible objects should be sorted and stored according to material type. Then separate storage environments could be created. This may be possible, but it depends on the use of the collections, and especially the involvement of the collection manager and curator. A curator is more likely to want a collection from say an archaeological site or historic house kept together, rather than being split into material type. It also depends on the availability of funds and adequate storage space to provide different storage environments. If such environments are available, then care must be taken in transferring an object from one environment to another, as stresses may be caused to the object due to rapid changes in T and RH. In particular condensation must be avoided. For these reasons it is unlikely that small museums will be able to afford the luxury of different storage areas for different materials, and therefore the approach will be to provide a storage area which will reflect the general environmental requirements of the museum, but hopefully provide a more stable and safe environment.

Storage units, like display cases, must not be located against walls, especially if these are outside walls to the museum building. Adequate space is required between units to allow air movement if necessary.

The materials of construction of storage units and containers follow the same principles as for display cases (section 10.3.). They must not release harmful chemicals and if possible should be absorbent to help buffer the RH, and be of neutral pH (or alkali buffered if acidic materials are being stored). Wood must be sealed (section 7.2.1.2.) to prevent the release of organic vapours therefore wood cannot be used for its moisture buffering capacity. Metal is more dangerous than wood in the event of a fire, due to the ‘oven effect’, whereby the heat of the fire is rapidly conducted through the metal cabinets extending the effects of the fire. However, metal is normally preferred to wood as a material of construction, but is usually more expensive.

Close wrapping of objects in archival or acid free paper is common practice to provide a barrier against air pollutants, high light levels, insects and abrasion, and to also add to the RH buffering capacity of the storage system. Although useful for collections in most climates, it is not recommended for hot humid climates, as the wrapping materials will hold moisture creating a microclimate which may be higher than outside the container. Also insects are attracted to the starchy components of paper. On the other hand, the storage of organic materials (e.g. ethnographic collections) in plastic bags has been found to provide a very stable level of RH due to the buffering capacity of the material.

10.2.1. T and RH

In order to provide a stable level of T and RH in a store room, it is first necessary to have as stable an environment as possible in the museum building, and to avoid extremes of temperature on and in the room.

The location of the storage room is important, as if on an outside wall, then as with display cases, the solar gain on the wall will be conducted into the room, causing a corresponding change in RH. If a wall is comparatively cold, then there may be problems of condensation. It is therefore advisable to locate store rooms in a central position in the museum, to enable the surrounding rooms to provide an environmental buffer. If this is not possible then a room should be chosen which is protected against solar heating, but which will not have condensation problems. The use of basement areas for storage is quite common, and this is more likely in a hot dry climate where the thermal sink of the ground will provide a more stable temperature. This is more difficult in a hot humid climate where buildings are often raised off the ground to enable air to flow under the building. If ever underground storage is used, care must be taken that the room cannot be flooded by heavy rain or rising water, and that rising damp is not a problem.

Especially in hot humid climates where air movement is used to prevent mould growth (section 8.1.2.), it is usual to store objects on open shelves. Storage units should be located away from the walls, and there should be adequate space between storage units and also between shelves for air movement from. The units should be arranged parallel to this air flow so that the flow is not hindered by the shelves and their contents.

The use of conservation heating, whereby the air is heated or cooled to adjust the RH, has been tried in museum storage areas, with varying degrees of success. This system avoids the need for humidification and dehumidification, relying on heating the air to reduce the RH in a hot humid climate, and cooling the air to increase the RH in a hot dry climate. Obviously care must be taken that that any heating or cooling is gradual so as not to cause any sudden changes in RH.

Moisture absorbent objects will control the RH of the immediate environment if they are reasonably well sealed in boxes, which if of cardboard should be of archival quality material or be alkali buffered to neutralise any acidity present in the organic materials.

Library and archive materials are usually stored this way and often produce an acceptable environment in the store room. If plastic containers are used care must be taken that there are no sudden drops in temperature which might cause condensation. The plastics must also be inert (section 10.3.). An extension of this is to store objects in metal cabinets (wood if unsealed may release harmful vapours), or on open shelves which are covered by plastic or cotton sheets (again not possible where air movement is used). Curators prefer plastic as they can visually locate an object, whereas a cotton sheet will necessitate good object location records for easy access to objects. So here it is necessary to have a small volume of air and a large volume of organic material to get adequate buffering of the RH by the object material. The amount of moisture movement in and out of the object required to provide this stable environment is so small that stress will not be placed on the object. As discussed in section 9, moisture buffering materials can also be used in the materials of construction of the store room, eg absorbent wall finishes.

10.2.2. Light

No natural daylight and in particular direct sunlight should be allowed to enter a store room. As the room will only be used on occasion, then the illumination and UV levels will not be significant compared to display areas (section 10.1.2.). Lights should be arranged so that only those sections to be visited in the store room are turned on, and notices placed to remind users to turn off the lights. The use of time switches is not recommended as a person could suddenly be left in the dark, although this can be avoided if safety lights are available.

It is important that illumination levels are high enough to enable objects to be examined, and again as only for a short period of time the levels detailed in Table 4.1, section 4.2, do not need to be adhered to. A level of about 500 600 lux is necessary to see the detail on the surface of an object, but as only for a few minutes, due to the reciprocity factor (lux times hours) this will not cause any damage to the object. UV levels should be as low as possible through the use of low UV lights or UV filters. It is normal to use low UV output fluorescent lights or perspex covered normal fluorescent lights in store rooms as they will not introduce heat into the room. Fluorescent lights should be arranged so that the light falls on the shelves of storage units and is not wasted covering tops of units.

10.2.3. Air pollutants

Controlling air pollutants in these areas will require similar strategies to those employed in other areas of cultural buildings, ie controlling indoor pollutant sources, minimising ingress of urban air pollutants, and air cleaning. There may be scope for operating these areas at low ventilation rates as they are unoccupied.

If store rooms are kept closed with reasonable door seals, then this will help to reduce the levels of air pollution in the room. This will be reduced even further by the use of containers or sealed storage units, however, if boxes are open or in the case of boxes for archive materials which contain a hole to pull out the box from the shelf, then this is sufficient to allow in air pollution. In hot dry climates where the major pollutant is likely to be particulate matter, cotton sheeting is the preferred material for covering shelving units as this can easily be washed. This is better than plastic or paper which can transfer the dust to the object.

10.2.4. <u>Pests</u>

Integrated Pest Management (section 7.2.3.1.) as applied to the museum building is essential for store rooms. What is important, however, is that the collections must be inspected on a regular basis. It is different for displays where museum staff are likely to see damage quickly, but objects in storage will not normally be seen except by chance. The use of insect traps (section 7.2.3.2) and rodent baits is essential, to monitor for the presence of pests and as the first line of pest control.

10.3. Materials of Construction for display cases and storage units

Materials used to construct display cases and storage units will include metals, woods, adhesives, sealants, coating systems and lining fabrics. They should be as stable and inert as possible so that they do not produce any air pollution such as volatile organic compounds (VOCs), or if in contact with objects do not cause any damage. It is just as important to select safe materials used for mounting or supporting objects on display or in storage such as wires, pins and tapes, as these will come into contact with the object, in addition they should not place stress or strain on the object. Ideally all materials should be tested before use, but if this is not possible, then the following guidelines will indicate which are potentially harmful and which are safe materials.

Before objects are placed in new display cases or storage units the materials of construction should be allowed to fully cure and dry, and this may take several weeks for coatings, adhesives and sealants.

The following materials are in general <u>unsafe</u> for use for constructing display cases or storage units:

- *adhesives* one-part epoxies, polysulphides, polyvinyl acetate (PVA), polyvinyl chloride (PVC), cellulose nitrate, urea formaldehyde, Blu-tack ®;

- *coatings* alkyd or oil-based paints, oil-modified coatings and varnishes, one-part epoxies, and chlorinated rubber;

- *metals* iron (mild steel) if uncoated;

- *nylon or polyester* fishing line for suspending objects (it can stretch or break);

- *paper* if acidic, such as newspaper and cardboard;

- *plastic products* polyvinyl acetate (PVA) and polyvinyl chloride (PVC) films and sheet;

- *sealants* acid-curing silicones, urea formaldehyde, natural and synthetic rubber;

- *textiles* if coloured or pre–treated with fire-retardant chemicals;

- *wood* most hardwoods, in particular oak, teak, chestnut, Douglas fir, red cedar;

- *wood composites* particle board, chipboard, interior grade plywood and fibreboard - depending on the adhesive used in their construction, with phenol formaldehyde which is used for exterior plywood being safer than urea formaldehyde; and

- *wool* including wool felts;

The following are considered safe, and may be used in combination, for example wood products can be coated to ensure any harmful volatile gases are sealed in:

- adhesives certain acrylics, two-part epoxies, starch paste, animal glues

- ceramics and glass;

- coatings acrylic lacquers, water-based vinyl acrylics, two component epoxies and urethanes, moisture-cured urethanes and air-drying enamels;

- metals aluminium, brass, bronze, stainless steel (including pins), coated mild steel;

- nylon or polyester-coated steel wires (for suspending objects);

- paper acid-free paper, tissue and board;

- plastic products polyethylene (PE), polypropylene (PP), polycarbonate, polyester cloth (*Stabiltex*), and film (*Mylar* or *Melinex*), acrylic textiles and sheet, *Dacron* wadding or fibre, *Foamcore*;

- plastic laminated panels such as *Formica* and *Micarta*;

- sealants neutral-curing silicones, polyethylene foams;

- textiles unbleached and undyed cotton and linen, polyester, nylon;

- wood certain species such as beech, birch, and perhaps hoop pine; and

- wood composites exterior grade plywood.

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BIBLIOGRAPHY

Baker, N.V. (ed) (1987) *Passive and Low Energy Building Design for Tropical Island Climates*, Commonwealth Science Council, London.

Ballard, M.W. (1994) *Geography and Textile Storage,* Pamphlet, Conservation Analytical Laboratory, Smithsonian Institution, Washington, D.C.

Bravery, A.F. (1981) 'Origin and nature of mould fungi in buildings', in *Mould Growth in Buildings,* Proceedings of a joint Building Research Establishment/ Paint Research Association Seminar, Princes Risborough, 1980, p2-13.

Brimblecombe, P. (1990) 'The composition of museum atmospheres', *Atmospheric Environment*, Vol.24B, p1-8.

Brimblecombe, P. and Nicholas, F. (1995) 'Urban air pollution and its consequences', in *Environmental Science for Environmental Management*, John Wiley & Sons, New York, p283-295.

Brown, S.K. (1997) 'Indoor Air Quality. Australia: State of the Environment Technical Paper Series (Atmosphere)'. *Environment Australia*, Canberra.

Cass, G.R., Druzik, J.R., Grosjean, D., Nazaroff, W.W., Whitmore, P.M. and Wittman, C.L. (1989) 'Protection of works of art from atmospheric ozone', *Research in Conservation,* No.5, The Getty Conservation Institute, Los Angeles.

Cassar, M. (1995) *Environmental Management: Guidelines for Museums and Galleries,* Museums and Galleries Commission, Routledge, London.

Cassar, M. (ed) (1996) *Museum Collections in Industrial Buildings: A Selection and Adaptation Guide,* Museums and Galleries Commission, London.

Christoffersen, L.D. (1995) *Zephyr: Passive Climate Controlled Repositories - Storage Facilities for Museum, Archive and Library Purposes,* Lund University, Sweden.

Edwards, D.W. and Walston, S. (1977) Biodeterioration of Wood, in *Conservation in Australia,* Proceedings of the AICCM National Conference, Canberra, 1976, S. Walston (Ed), p64-76.

Eremin, K and Wilthew, P. (1996) 'The effectiveness of barrier materials in reducing emissions of organic gases from fibreboard: results of preliminary tests', in *Preprints of the ICOM-CC 11th Triennial Meeting, Edinburgh,* ICOM-CC, Paris, p27-35.

French, J. (1991) *Organic Control of Household Pests,* Aird Books, Flemington.

Frost, M. (1991) 'Planning for preventive conservation', in *The Manual of Museum Planning,* HMSO, Norwich, p127-160.

Fuji-Davison (1986) *The Function of Art-Sorb,* Technical Bulletin, Fuji-Davison Chemical Ltd, Japan.

Grzywacz, C. and Tennent, N.H. (1994) ' Pollution monitoring in storage and display cabinets: carboxyl pollutant levels in relation to artefact deterioration'. in *Preventive Conservation Practice, Theory and Research*, IIC, Ottawa, p164–170.

Hillyer, L. and Blyth, V. (1992) 'Carpet beetles - A pilot study in detection and control', *The Conservator,* No.16, p65-77.

Hollo, N. (1995) *Warm House Cool House,* Choice Books, Sydney.

Lanting, R.W. (1990) 'Air pollution in archives and museums: its pathway and control'. *Proceedings of Indoor Air ’90*, Vol. 3, pp665–670.

Lesiuk, S. (1983) 'Landscape design for energy conservation in the middle east, in *Islamic Architecture and Urbanism*, A. Germen (ed), Damman: King Faisal University, p215-231.

Michalski, S. (1994(a)) 'Relative humidity and temperature guidelines: what is happening?', *CCI Newsletter,* No.14, September, pp6-8.

Michalski, S. (1994(b)) 'A systematic approach to preservation: description and integration with other museum activities', in *Preventive Conservation Practice, Theory and Research*, Preprints of the Contributions to the Ottawa Congress, IIC, London, pp8-11.

Miles, C.E. (1986) 'Wood coatings for display and storage cases', *Studies in Conservation,* Vol.31, pp114-124.

NAFI (1989). *Timber Manual, Vol.1 and 2*. National Association of Forest Industries, Canberra.

O’Brien, B. (1996) *Guidelines for Environmental Control in the Galina Beek Cultural Centre at Healesville,* Museum of Victoria, Melbourne.

O’Sullivan, P. and Oreszczyn, T. (1992) 'Environmental control in historic galleries and museums'. *Indoor Envir*. 1, pp363–366.

Olgyay, V. (1963) *Design with Climate,* Princeton University Press, New Jersey.

Padfield, T. (1987) 'Climate control in libraries and archives', in *Preservation of Library Materials,* Proceedings of the Vienna Conference, 1986, M.A. Smith and K.G. Saur (eds), Munchen, pp124-138.

Padfield, T., Erhardt. D. and Hopwood, W. (1982) 'Trouble in store', in *Science and Technology in the Service of Conservation,* Preprints of the 9th International IIC Congress, Washington D.C., IIC, London, pp24-27.

Pearson, C. (1988) 'The problems of environmental control in Pacific Island museums', in *Control of Museum Climate in Asia and the Pacific Area,* The Japanese Organising Committee of the IIC Kyoto Congress, Kyoto, pp46-49.

Pinniger, D. (1994) *Insect Pests in Museums,* 3rd Edition, Archetype Press, London.

Preusser, F. (1997) 'Report on Conference on Collections Environments', *Cons DistList* (www site), 11 Sept. 1997.

Rogers, P. (1997) *Safer Pest Control for Homes and Gardens,* Choice Books, Marrickville.

Saini, B.S. (1980) *Building in Hot Dry Climates,* John Wiley & Sons, New York.

Saunders, D and Kirby, J. (1996) 'Light-induced damage: investigating the reciprocity principle', in *Archaeological Conservation and its Consequences,* Preprints of the ICOM-CC 11th Triennial Meeting, Edinburgh, ICOM-CC, Paris, pp87-90.

Scott, G. (1994) 'Moisture, ventilation and mould growth', in *Preventive Conservation Practice, Theory and Research*, Preprints of the Contributions to the Ottawa Congress, IIC, London, pp149-153.

Scott, G. (1996) 'Mould growth in tropical environments: a discussion', in *Archaeological Conservation and its Consequences,* Preprints of the ICOM–CC 11th Triennial Meeting, Edinburgh, ICOM-CC, Paris, pp91-96.

Strang, T.J.K. (1992) 'Museum pest management', in *A Systematic Approach to the Conservation (Care) of Museum Collections,* S. Michalski (ed), Canadian Conservation Institute, Ottawa.

Strang, T.J.K. and Dawson, J.E. (1991) 'Controlling museum fungal problems', *Technical Bulletin, No.12,* Canadian Conservation Institute, Ottawa.

Szokolay, S.V. (1982) *Climate Data and its Use in Design,* Royal Australian Institute of Architects, Canberra.

Szokolay, S.V. (1987) *Thermal Design of Buildings,* Royal Australian Institute of Architects, Canberra.

Tétreault, J. and Williams R.S. (1992) 'Materials for exhibit, storage and packing', in *A Systematic Approach to the Conservation (Care) of Museum Collections,* S. Michalski (ed), Canadian Conservation Institute, Ottawa.

Thomson, G. (1986) *The Museum Environment,* (2nd Edition), Butterworths, London.

Waller, R. (1994) 'Conservation risk assessment: a strategy for managing resources for preventive conservation', in *Preventive Conservation Practice, Theory and Research*, Preprints of the Contributions to the Ottawa Congress, IIC, London, pp12-16.

Waller, R. (1996) 'Preventive conservation planning for large and diverse collections, in *Preservation of Collections: Assessment, Evaluation and Mitigation Strategies*, Papers presented at the Workshop, Norfolk, Virginia, American Institute for Conservation, Washington, D.C., pp1-9.

Weintraub, S. (n.d.) *Art Restoration Services Catalogue*, New York.

Wood Lee, M. (1988) *Prevention and Treatment of Mould in Library Collections with and Emphasis on Tropical Climates: a RAMP Study*, UNESCO, Paris.