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CONTROLLING THE ENVIRONMENT IN MUSEUMS IN THE UNITED KINGDOM
with special reference to Relative Humidity and Temperature

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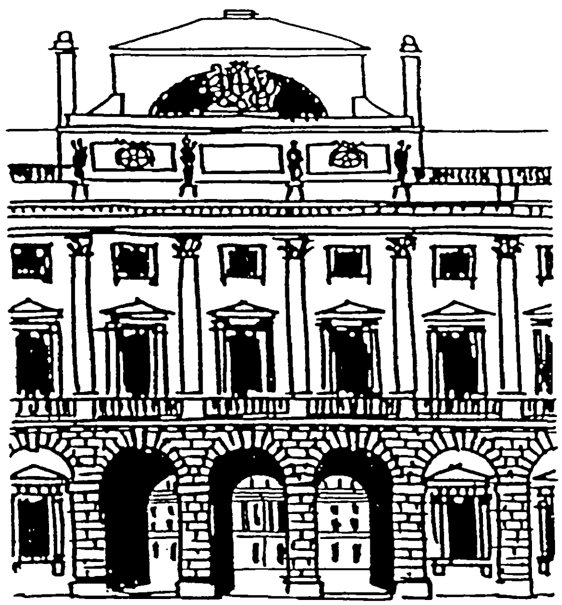

COURTAULD GALLERIES AT SOMERSET HOUSE
STRAND ELEVATION CHRISTOPHER FIRMSTONE

Submitted in part fulfillment of the requirements for
the degree of Master of Science in Architecture
(Environmental Design and Engineering)

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To my husband, Kazik

Contents

ABSTRACT

This report discusses the emphasis that should be given to environmental control in museums where historically unique and climatically sensitive objects are displayed and stored in perpetuity.

The environmental conditions that should be provided for a range of museum objects are compared to those required by people. The differences and similarities in their respective environmental requirements and the choice between an active and passive approach to climate control are investigated.

A discussion of the conversion of the Strand Block of Somerset House for use as an art gallery by the Courtauld Institute of Art illustrates the problem of reconciling the nature of historic buildings with their use as museums and the difficulties of providing suitable conditions for objects and people. The report concludes that a strategic approach to environmental control is required to achieve a balance among the requirements of objects, people and the building.

ACKNOWLEDGMENTS

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PREFACE

A controlled museum environment is just one of a range of specialist environments that architects and building services engineers may be called upon to design. Tightly controlled environments are required by people in operating theatres in hospitals, by exotic plants in greenhouses and conservatories such as at the Royal Botanical Gardens in Kew and for special processes in pharmaceutical clean rooms and computer suites. The tightly controlled conditions required for special processes come closest to the need to provide controlled conditions for objects in museums because in both cases priority is given to objects or processes rather than people.

However, unlike the buildings in which specialist processes are carried out, museum collections are not often housed in purposely constructed buildings which facilitate environmental control. They are found in a variety of buildings ranging from historical, listed buildings for display to industrial warehouses for storage. These can make the provision of a tightly controlled environment for objects and simultaneously, a suitable environment for people, difficult to achieve. This situation is made more difficult when the museum is housed in a historic building which is itself an object worthy of preservation. On top of all this, museums often lack the resources to create the specialist environmental conditions which are needed.

This report discusses the main issues relating to the provision of environmental controls in museums in temperate climates, as the United Kingdom. The use of the word 'objects' throughout this report means both artefacts that is hand- or machine-made objects, and specimens that is objects of natural or scientific importance. The terms 'museum' and 'art galleries' are mutually interchangeable.

CHAPTER 1

THE CHANGING ROLE OF MUSEUMS AND ITS EFFECT ON THE BUILT ENVIRONMENT

The key purpose of museums is to preserve the building contents for future generations. The contents consist of collections of objects of varying age and condition. Although all materials have a finite life, it is the museum's responsibility to ensure that measures are taken to maintain the physical stability of objects for as long as possible, by slowing down the processes of decay.

Objects can be affected by one or a combination of three different modes of deterioration: physical, chemical and biological damage. Dimensional changes in size, shape and weight of objects occurs when hygroscopic materials such as wood, expand at high relative humidities (RH) and contract when RH falls. Irreparable damage such as warping or cracking can take place. Excessive heat causes some materials such as wax to soften or even melt.

The corrosion of metals is caused by a chemical reaction of the material with moisture at high relative humidities. Photochemical damage caused by visible light and ultraviolet radiation causes dyes to fade and some natural fibres such as silk to become brittle and weak.

All organic materials are at risk from biodeterioration. Insects find many museum materials a ready food source, while fungal and mould attack are more likely in high humidities[1].

Inappropriate environmental conditions are therefore a serious and insidious cause of damage because once decay has started it tends to accelerate rather than stop.

The rate of decay is not the same for all museum objects. Materials such as ceramics, glass and stone decay very slowly. The normal process of decay may only become apparent over many years, consequently they are normally classed as 'stable' materials. Many other materials or combination of materials, such as manuscripts on vellum and paintings on wood panels respond more quickly to a changing environment and they can deteriorate rapidly unless they are kept in controlled conditions.

The traditional role of museums has been the display of the collection and activities related to its research and interpretation. In recent years there has been a marked expansion in the role of museums and in the use of collections. Changes are taking place in museums of different sizes partly in response to encouragement to museums to market themselves more effectively and partly due to economic pressure to generate income.

A recent Audit Commission report on local authority museums[2] suggests how they should go about managing their public role more effectively. The report recognised that capital and revenue investment in museums would be required, but it also recommends judicious use of museum assets which include the collection.

What options are open to museums to raise funds?
This study which focuses on the environmental needs of museum collections will concern itself only with those options that directly or indirectly affect museum collections.

Among the options that can indirectly affect the collection are site management and marketing, areas which museums are encouraged to include in their business or development plans.

Restaurants, cafes and museum shops have been opened in some museums, while conference suites can be found in a handful of museums. Concern for the collection arises in situations where no measures are taken to isolate the environment of the collection from the environment in the commercial areas.

Among the fund-raising options available to museums, which directly affect the preservation of the collection are disposal of objects, special openings of the galleries for private functions, public access to storage areas and fee charging by museums for the loan of objects to other institutions. These options are discussed in more detail below.

Disposal of objects from museum collections, other than the transfer of objects between museums is clearly controversial. Disposal may include exchange, sale, gift, loan or destruction. Some of these methods of disposal may be acceptable in certain circumstances, others are obviously not. The Audit Commission report mentioned above, states: 'Museums may also need periodically to renew their collections, acquiring new objects and disposing of unwanted ones..'[2]. The report considers this good management practice, making choices where only finite resources are available. It states also that 'many councils cannot now look after their collections properly and are, in effect, disposing by decomposition'[2]. This report undoubtedly exposes a key management problem. The Museums & Galleries Commission[3] and the Museums Association[4] are likely to approve of the disposal of objects for which a museum recognized it could not adequately care. But there should always be sound curatorial reasons for sales from the collection and the sale of objects to generate income for the museum is not an acceptable reason.

Museums have found other methods of raising funds without resorting to the sale of objects. The hire of gallery space for private functions and corporate entertainment where the collection on display serves as an interesting and unusual backdrop, is increasing. Sometimes the limit on the number of guests at any one function is determined by floor-loading restrictions in old museum buildings, the physical safety of objects on display or the maintenance of thermal comfort conditions for guests. Recently, one London gallery had to curtail its private events programme because of fears that environmental instability caused by the presence of large numbers of people might damage the paintings on display.

The use of gallery space for non-museum functions has for the first time brought the public role of museums into conflict with their traditional role. The additional security risk to the collection posed by these activities is an obvious area of potential conflict. The collection on display may be at risk from another cause of damage not present during regular opening hours, the spillage of food or drink during private functions.

People are also gaining more access for longer periods of time to locations in the museum which until recently were used exclusively by collections. Experience in North America with putting reserve collections in visible storage has had mixed success. Visible storage combines two functions that are normally considered separate - display and storage. Visible storage is potentially more damaging to objects than traditional storage and display. The major concerns are increase in light levels and prolonged exposure to light, as opposed to dark, closed storage and relative humidity and temperature problems with objects in visible storage similar to those found in objects on display[5]. Visible storage may be appropriate only for stable objects because it gives the needs of visitors equal standing with the conservation of the collection.

The loan of objects from one museum to another or several others is an accepted way of making items from collections accessible to a wider public. For museum lenders who impose hire charges for the loan of objects which are in great demand, this can also be a source of revenue. However, transporting objects to several exhibition venues can present potentially the highest environmental risk to the object. This is because unless the environment in the lending museum is carefully assessed and the environment in transit and at the receiving venues is carefully planned, the objects may be subjected to different climates which can be stressful to the materials, within a relatively short space of time at each phase of the tour[6].

The environmental risks to which collections are exposed as a result of diversification of the museum's activities are often not properly evaluated and costed. These risks include:

i. the increased exposure time of the collection to the damaging effect of light

ii. the impact of large numbers of people on the ambient environment within a space causing an increase in heat, moisture and pollutants over a period of time

iii. the risk of pest infestation as a result of food residues from private functions

iv. the instability caused to objects by the loss of their equilibrium with the environment when they are loaned to other museums.

The changes to collection management described above are taking place against a background of increased awareness of the measures needed to preserve museum objects. The traditional emphasis of collection care has been on the remedial conservation of objects. The approach that 'prevention is better that cure' is becoming widely prevalent. A better understanding of the causes of deterioration and the mechanisms of decay over the last decade has led to a recognition of the need for tighter control over the indoor museum environment.

The basic principles which museums should adhere to, to avoid environmental damage to the collection are:

i. minimum exposure to light and ultraviolet radiation for light-sensitive objects such as paintings and textiles

ii. constant relative humidity and temperature for objects made of organic materials such as wood, ivory and parchment, and objects made of inorganic materials such as ceramics, glass and stone but excluding metals
iii. minimum relative humdity for metallic objects
iv. reduction of air movement for objects with delicate surfaces such as pastels and charcoal drawings
v. the control of pests which can attack organic materials
vi. exclusion of externally generated gaseous and particulate pollutants, the control of pollutants released by occupants and the control of off-gassing from unstable materials which can affect all types of materials whether organic, inorganic or metallic objects.

This study concentrates on examining the second and third principles listed above because the changes in use which are taking place in museums are having the greatest impact on the stability of ambient relative humidity and temperature, with potential serious consequences for the objects housed within these buildings.

References

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2. The Audit Commission, **The Road to Wigan Pier? Managing Local Authority Museums and Galleries**, HMSO, 1991.

3. The Museums & Galleries Commission has been the Government's main adviser on museum matters since 1931. Its offices are at 16 Queen Anne's Gate, London SW1H 9AA.

4. The Museums Association, an independent charitable organisation and the world's first association of museums and galleries, was formed in 1889. It is based at 34 Bloomsbury Way, London WC1A 2SF.

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CHAPTER 2
CONTROL FOR OBJECTS AND PEOPLE

The responsibility vested in museums to preserve objects in their care has been discussed in Chapter 1. Environmental control within museums should therefore achieve and maintain appropriate conditions for the preservation of a wide range of natural and synthetic materials, while also fulfilling the legal obligation to provide conditions for human health and comfort. The differences and similarities between conditions for human comfort and 'object comfort' will be discussed in this chapter.

CONDITIONS FOR OBJECTS

Environmental control within museums is aimed primarily at providing suitable conditions for the collection. If museum collections were composed entirely of homogeneous materials, this would be relatively simple to achieve. However, this is rarely the case. Providing a controlled environment for objects requires knowledge and application of established principles, and knowing when and what compromises can be made in order to benefit the collection without ignoring the needs of visitors and staff.

At the end of Chapter 1 brief reference was made to the two main classes of materials from which all objects, including museum objects, are made. These are organic materials, that is materials of animal or vegetable origin and inorganic materials, that is materials of mineral origin. All natural materials are included in these two broad classes.

To these should be added synthetic materials, for example, imitation ivory made of cellulose nitrate which as an early plastic material, was used for cutlery handles and dressing table sets in the first half of the 20th century and which now form part of local history collections.

Museum objects can be made of single materials or combinations of materials, each of which will respond differently to changes in environmental conditions depending on how individual materials have been treated and used, and the physical condition of the objects. Therefore the answer to the question, what are the environmental conditions required by objects, is complex. The environmental control criteria will vary depending on the material, construction and condition of the objects. The criteria which have found concensus in museums are embodied in a seminal work on the museum environment first published in 1978 by Garry Thomson, then Scientific Adviser to the National Gallery, London[1]. This reference work discusses in detail the environmental requirements of museum objects. The conditions required by different museums materials are summarised in the following table:

Materials/ Objects	**Environmental Conditions on Display**			
	Relative Humidity			**Temperature**
	Upper	**Lower**	**Constant**	
Hygroscopic Materials	65%	45%	c.55%	Room Temperature
Historic Metals	<40%	N/A	N/A	Room Temperature
Archaeological Metals esp.iron	<20%	N/A	N/A	Room Temperature
Mixed Materials	60%	40%	c.50%	Room Temperature

Elsewhere, Thomson recommends that, 'the proportion of dirt reaching the exhibits (should be) well below 5% by weight of the outside levels' and that gaseous pollution should also be controlled, with ozone reduced to trace levels and sulphur dioxide and nitrogen dioxide reduced to no more than 10 $\mu g/m^3$ [2]. These criteria serve as a useful guide to the conditions required by different materials.

However, there are three main principles which should guide every decision to create appropriate conditions or to improve environmental controls in museums:

i. The most important factor is the existing environment with which the collection has reached an equilibrium.
In planning environmental controls for the collection a workable compromise has to be reached between published standards which recommend ideal conditions and the environmental conditions that exist already. Any solution must avoid rapid fluctuations in relative humidity and temperature and should include steps to control light, gaseous and particulate pollution.

ii. The move of a collection from one set of conditions to another should be as gradual as is practicable in order to give the materials time to climatise to the new conditions.
The faster the speed of climatic changes and the wider the band of tolerance within which it fluctuates, the faster is the rate of decay of materials subjected to these conditions.

iii. Measuring the rate of decay of materials is fraught with difficulties. It is difficult to link the rate of deterioration of materials with the speed of indoor climatic changes since it also depends on the composition and condition of the object. Ancient or historical materials respond to climatic changes in the same way as modern materials. But with some materials such as archaeological metals, the process of decay tends to accelerate once it has started. Furthermore, it can be very difficult to obtain samples of original material on which to experiment.
The indoor climate should be permitted to fluctuate as little as it is practicable to maintain, within the bands of tolerance outlined in the above table.

CONDITIONS FOR HUMANS

Museums have a legal responsibility and a duty as public institutions to provide a suitable environment in which staff can work and visitors can enjoy the collection. Thermal comfort among humans combines both subjective perception and objective measurement. The principal factors affecting human thermal comfort can be divided into two groups: the physical variables and the personal variables. The former includes air and radiant temperature, humidity and air movement and the latter includes activity and clothing[3].

Thermal Comfort Criteria

Legislation to regulate the maximum temperature to which public buildings are heated, to 19°C has been in place since 1980[4]. If this legislation were more effectively enforced in museums, it would reduce the amount of energy consumed and still provide thermal comfort conditions for both humans and objects.

The guidelines on thermal comfort in the Chartered Institution of Building Services Engineers (CIBSE) Guide are based on psycho-physical laws derived from laboratory and climatic chamber tests of human subjects. The CIBSE Guide suggests that in most practical situations where air movement is low, the acceptable Index Temperature for comfort is the average of air and mean radiant temperature. In 1978 CIBSE adopted dry resultant temperature as the Index Temperature for human comfort in the United Kingdom. Dry resultant temperature takes into account dry bulb temperature, mean radiant temperature and air speed as they affect thermal comfort. This led to the suggestion that for sedentary occupations,

> '..a majority of people will neither be warm nor cool in winter in rooms where the resultant temperature is between 19°C and 23°C when the air speed is less than $0.1m^{-s}$, (ie nominally still air)...and the relative humidity lies between 40% and 70%'.[5]

These conditions can be applied to the thermal comfort requirments of museum warders who work within exhibition spaces and also to the majority of visitors to museums. Although neither group has what can be strictly defined as a sedentary occupation, warders tend to spend most of their time standing or sitting while museum visitors usually walk very slowly through a museum pausing frequently to look at objects on display.

If the CIBSE criteria are used as a guide to human comfort needs in museums, attention needs to be drawn to the fact that these criteria are intended for the office environment where it can be assumed that outdoor wear such as overcoats and jackets are not worn. Not many museums however have cloakroom facilities and in those which do, use by visitors is optional. Therefore wearing or carrying heavy items of clothing can be considered quite common practice in museums which may have an operating temperature between 19° and 23°C. In these circumstances a lower operating temperature could benefit people carrying or wearing heavy clothing, would have the effect of slowing down the process of decay of materials and could also result in the provision of controlled conditions with lower energy consumption.

Ventilation and Pollution Control

Ventilation and pollution are both controlled for health reasons by legislation, and for comfort purposes because of human beings' sensory perception of indoor air quality. Two new units which quantify how air is perceived by human beings have been introduced. The olf quantifies the source strength of air pollution and the decipol quantifies perceived air pollution[6].

The Chartered Institution of Building Services Engineers (CIBSE) states that in museums, libraries and galleries, 'fresh air supply rates will normally be determined by the requirements of the occupants'[7].

The Health and Safety at Work Act 1974 (Section 2(2)(e)) requires the provision and maintenance of a working environment that is, as far as is reasonably practicable, safe and without risk to health. It protects not only people at work, but also the health and safety of the general public who may be affected by work activities. Minimum ventilation rates are not specified by statute but the Offices, Shops and Railway Premises Act 1963 (Section 7) requires the ventilation of every room in which employees work by the circulation of adequate supplies of fresh or artificially purified air. Maximum concentrations of indoor pollutants are covered by recommendations of the Health and Safety Executive. The long-term exposure limit (8 hours) for carbon dioxide is 5000 parts per million as legislated by the Control of Substances Hazardous to Health Regulations (COSHH) 1989. Guidance Note EH 22 from the Health and Safety Executive on 'Ventilation in the workplace' specifies that approximately 2 litres per second per person of fresh air is required to dilute exhaled carbon dioxide to the occupational exposure limit, 0.5%.

OBJECTS VERSUS HUMANS

How far do the environmental conditions required by objects, differ from those required by humans? The physical variables which affect humans also affect museum objects. There is however one crucial difference. This is that humans are temperature-sensitive whereas most objects found in museums are humidity-sensitive[8]. This is clear from a comparison of the environmental conditions required by objects as described by Thomson, with those required by humans as recommended in the CIBSE Guide, outlined earlier in this chapter.

Personal variables do not only apply to humans. Just as a human body responds to its surroundings, so too museum objects respond to ambient environmental changes. However, humans can take action to influence their environment, whereas objects cannot.

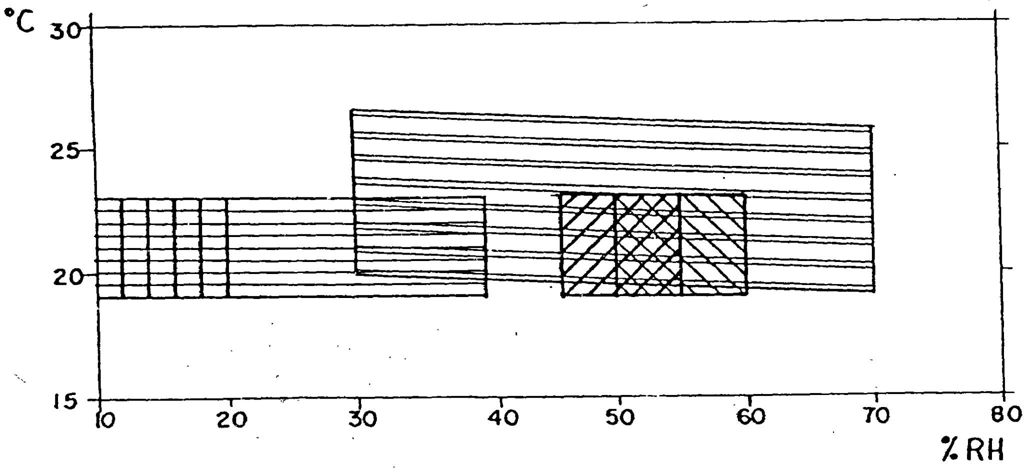
Humans can adapt to a thermally hostile environment by changing their pattern of activities or the amount of clothing they are wearing or by moving out of the space that is causing them thermal discomfort. Humans will also contribute to the creation of their own environment by releasing approximately 60 grammes of water vapour per hour and at least 60 watts of heat, both of which affect ambient relative humidity. They will also produce pollutants such as CO_2.

In contrast museum objects are passive recipients of the ambient environmental conditions which humans help create. They respond and adapt to the environmental conditions that are provided but they cannot alter them. If the ambient environment is suitable for the collection in the museum, its rate of decay will be imperceptible. If the environment fluctuates, many objects will deteriorate very quickly because the margins of tolerance of many materials is very much narrower than that of humans. 'For most materials...consistency is more important than the actual value'[9].

The similarities and differences between human-needs and object-needs are best illustrated by comparing and contrasting, their separate environmental requirements. The conditions for human thermal comfort recommended in the CIBSE Guide describe a narrow margin of tolerance for temperature changes and a wider one for relative humidity.

Numerous publications have suggested wider margins of tolerance for both temperature and relative humidity are possible. The broadest band stipulated a comfort range of 20°C to 28°C at 30% RH and 18°C to 26.5°C at 70% RH[10]. Using this range of conditions to define human thermal comfort, a chart (Figure 1) plotting both human comfort needs and 'object comfort' requirements as defined earlier in this chapter demonstrates clearly the similarities and differences between them.

Fig. 1: Chart plotting comfort requirements of objects and people



PEOPLE COMFORT RANGE

20° - 28°C at 30% RH
18° - 26.5°C at 70% RH

OBJECT COMFORT RANGE

	Temperature (Ø)	19° - 23°C
(vertical lines)	Archaelogical Metals	20% RH (max)
(horizontal lines)	Historic Metals	40% RH (max)
(diagonal hatching)	Mixed Materials	45% - 55% RH
(reverse diagonal hatching)	Hygroscopic Materials	50% - 60% RH

(Ø) as recommended by CIBSE

Mixed materials and especially hygroscopic materials require a constant relative humidity while metals require a low constant relative humidity. The human body is affected by irritation of the nasal passages, the throat and eyes if ambient relative humidity drops below 30%. It is otherwise tolerant of considerable variations in humidity until relative humidity rises above 70% at 20°C. At this level, relative humidity may cause some discomfort[11,12]. The human body is least sensitive within the band 30% to 70% RH. It is within this range that tight control over relative humidity is critical for a large number of museum objects, as can be seen from this chart.

The broad thermal comfort conditions that satisfy humans, can be applied to museum objects made of materials that are known to be slow to respond to environmental changes such as stone, highly-fired ceramics and historic glass. However, even these materials, if they are in an unstable physical condition may be vulnerable to accelerated decay if kept at the limits of the band of tolerance for relative humidity that humans find acceptable. An assessment of the condition of the objects by a conservator should provide an informed basis for decisions to be made on the appropriate environment that is needed.

'Object comfort' conditions for most museum materials lie within the human comfort zone. The main difference is that the margins of tolerance for objects are much narrower than for humans. Furthermore, the fundamental requirement for most museum materials is for very stable humidity control within a very narrow band which is difficult to achieve and maintain on a macroscale without major changes to the normal pattern of use within the museum. It is very difficult to provide satisfactory environmental conditions for both objects and humans occupying the same space within museums. The choices that are available are examined in detail in the following chapter.

References

1. Thomson, G, **The Museum Environment**, Butterworths, 2nd ed, 1986

2. **Ibid.**, p.129 and 151.

3. Clark, R P & Edholm, O G, **Man and His Thermal Environment**, Edward Arnold, 1985, pp.52-54 and pp.200-201.

4. Billington N S & Roberts B M, **Building Services Engineering A Review of Its Development**, Pergamon Press, 1982, p.20.

5. CIBSE Guide, **Design Data**, Volume A, p.A1-4.

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11. Chrenko, F A, ed, **Bedford's Basic Principles of Ventilation and Heating**, H K Lewis & Co Ltd, 1974, p.163.

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CHAPTER 3

PASSIVE CONTROL OF THE MUSEUM ENVIRONMENT

Arguements have been put forward at different times in favour of relying on the buffering capacity of the fabric of old buildings to stabilise internal environmental changes in museums.

> 'The walls of most historic buildings built of masonry are thick but permeable and generally have good total thermal resistance, though the materials themselves may be poor insulators. Their thermal mass is great....The mass of a historic building helps to protect its contents against violent environmental changes by 'damping down' the rate of change'.[1]

A building of heavy construction is thought to be inherently more environmentally stable than a lighter one. However the extent to which it succeeds also depends partly on its thermal mass and air infiltration rates which affect the transfer of heat and the movement of water vapour into and out of the building, and partly on external ambient conditions which are affected by the building's geographical location and its position on the site.

ENVIRONMENTAL BUFFERING BY THE BUILDING

Buffering is complex because it involves air infiltration, the construction of the building and whether the source of climatic variation is internal or external.

The buffering capacity of the building fabric is influenced by how long the temperature inside the construction element takes to respond to a temperature change at its external surface. This can be characterised by the time-lag of the construction. The buffering capacity is also affected by the rate of air infiltration. A high infiltration rate results in internal air temperature following external air temperature regardless of the response of the walls.

The same can apply to changes in moisture content, except that the main source of moisture transfer from outside to inside is by infiltration and not through the fabric[2]. Only the surface layers play a major part in moisture transfer. In theory, assuming a building is totally sealed, the longer the time-lag of the element, the greater is the buffering capacity of the building. The time-lag of a construction element increases with increasing thickness or distance from the surface, and decreases with increasing frequency of the temperature cycle at the surface and the thermal diffusivity of the element[3]. The thicker the element the greater is the time-lag. The greater the amplitude of temperature change at the surface and the lower the thermal mass of the element, the faster the response of the building to temperature changes.

Typical time-lag in hours, for external cycles of heat, for two homogeneous materials commonly used in traditional building construction are described below[4]:

Material	Thickness (mm)		
	100	200	300
Brick (min)	2.3	5.5	8.5
Brick (max)	3.2	6.6	10
Stone (average)		5.5	8.0

Theoretical Discussion

From the table above, external walls could be expected to have time-lags in the range from hours to days. For internal rooms that is ones surrounded by other rooms, the buffering capacity would be expected to be considerably longer. An indication of the buffering effect the construction may have on variations in external climate has been obtained by averaging hourly Kew weather data over different periods varying from 12 hours to 1 month, for a period of 1 calendar year (**Figures 1-5**), based on

Figs. 1-5: Averaged Kew weather data for 1 calendar year based on a test reference year[5]

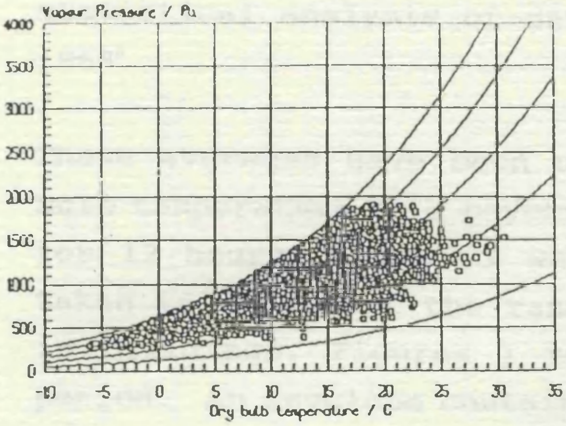


Fig. 1: Hourly

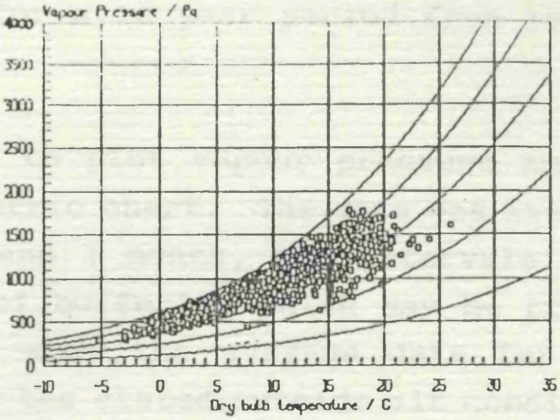


Fig. 2: 12 - hourly

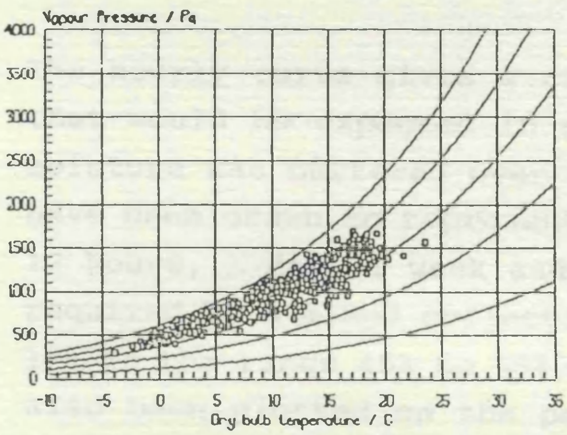


Fig. 3: Daily

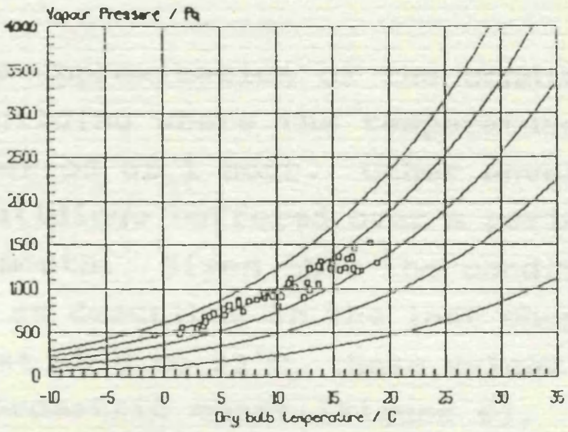


Fig. 4: Weekly

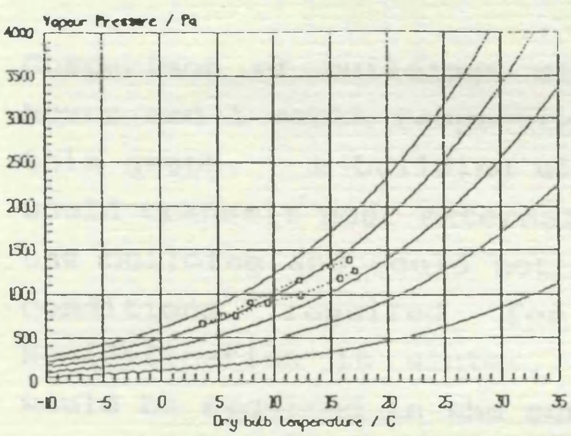


Fig. 5: Monthly

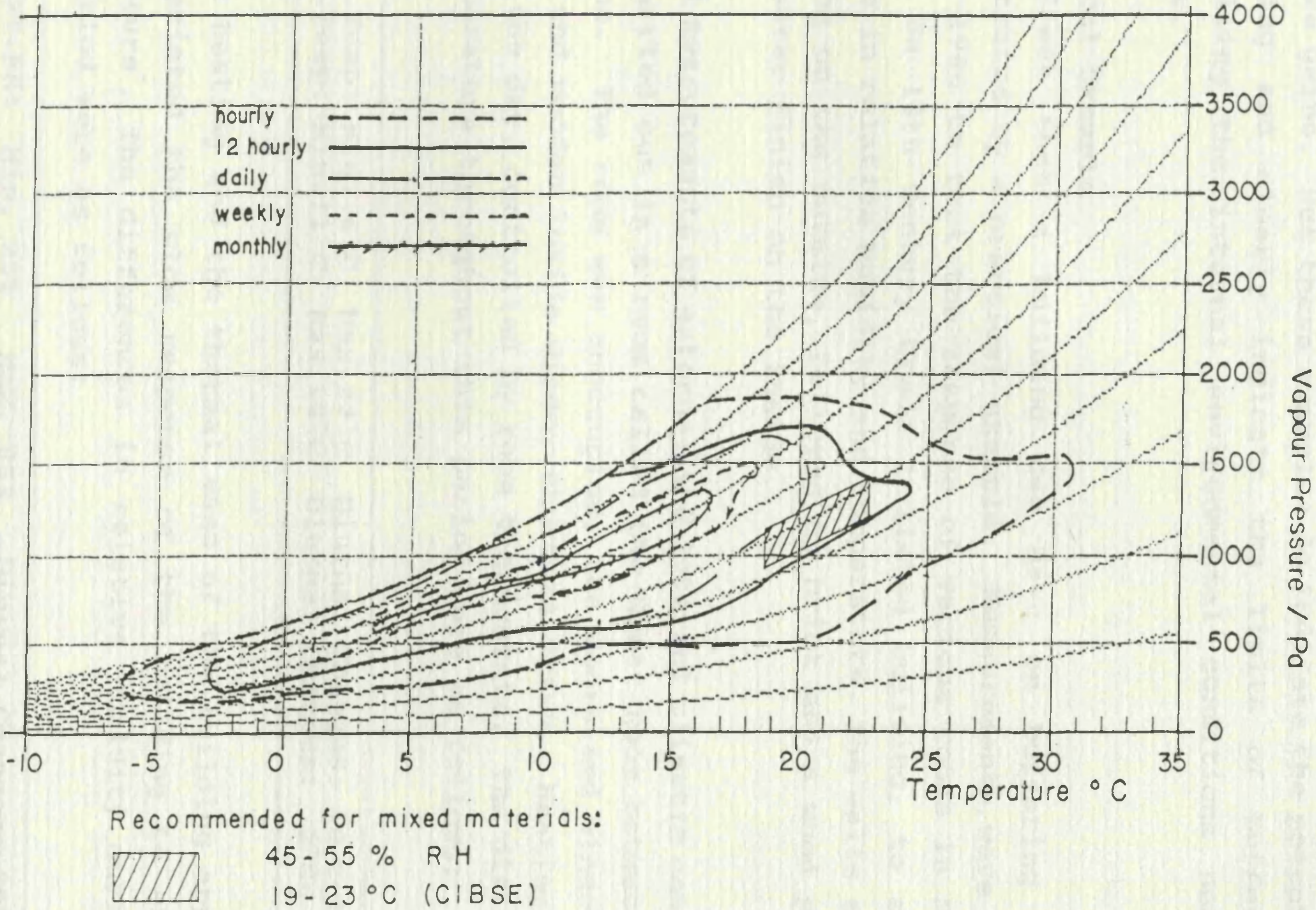
analysis of a test reference year[5]. This was established from statistical analysis of data for a 10 year period from 1959 to 1968[6].

These averages have been used to plot vapour pressure and dry bulb temperature on a psychrometric chart. The data was averaged for 12 hours, 1 day, 1 week and 1 month, the intervals being taken to represent the range of buffering which may be present in buildings. Figures 1 to 5 show the average data for each period. An envelope containing the stated outside air conditions was then drawn around the values for each specific time interval on a separate psychrometric chart (**Figure** 6).

The hourly curve gives a crude approximation of the conditions that would be expected in a building where the temperature and moisture was buffered over a period of 1 hour. Other envelopes have been drawn to represent buildings buffered over a period of 12 hours, 1 day, 1 week and 1 month. Given that the conditions required by a mixed collection as described in the last chapter, lie in the range 45% to 55% RH at 19°C to 23°C, these values have also been plotted on the psychrometric chart (**Figure** 6). They lie within the envelope of a building with characteristic buffering of 12 hours.

Comparison of buildings with buffering characteristics of 12 hours and 1 month respectively have also been carried out from this graph. A building with a buffering capacity of 12 hours would transmit most external climatic changes to the interior of the building and could not be relied upon to keep the internal conditions required for objects without heating and humidification in winter, while cooling and dehumidification would be required in the summer. In a building with a time-lag of 1 month on the other hand, heating and humdification are needed to provide 'object' comfort conditions but no cooling or dehumidification would be required.

Fig. 6: Hourly Kew weather data for 1 calendar averaged over periods of 12 hours to 1 month and plotted as vapour pressure and dry bulb temperature on a psychrometric chart



The above is a considerable over-simplification. In reality such situations would have to take into account internal heat and moisture gains. But these examples do indicate the potential for buffering and clearly indicate the limits of buffering in controlling the internal environmental conditions needed in museums.

Practical Example

The effect that a building can have on buffering can be demonstrated by a practical example. Measurements were carried out in 1986 to test the response of various rooms in Somerset House, an 18th Century Grade 1 listed building, to external changes in relative humidity and temperature. The walls are made of stone on the outside, followed by brick and a wood panelled and plaster finish on the inside.

Initial measurements of external and internal climatic conditions were carried out in a room called the Great Room between April and June. The room was unoccupied, the doors and windows were closed and wooden inside window shutters drawn. Heating was on during the day, controlled by room thermostats. The differences in temperature throughout this period were as follows:

Ext.Temp:	Min. 6°C	Max.22°C	Diurnal Changes: 10°C-12°C
Int.Temp:	Min.11°C	Max.19°C	Diurnal Changes: 2°C- 3°C

Daytime heating and the thermal mass of the building appear to have assisted the slow response of the building to external temperature[7]. The differences in relative humidity durimg the same period were as follows:

Ext.RH:	Min. 25%	Max. 85%	Diurnal Changes: 50%
Int.RH:	Min. 32%	Max. 70%	Diurnal Changes: 30%

While internal relative humidity responded fairly quickly to changes in external RH, the amplitude of the curves was reduced considerably[8]. This can be seen from the example of the graphs for indoor and outdoor relative humidity and temperature for 17th May (**Figures 7-8**).

Changes in relative humidity are caused by changes in temperature and moisture content of the air. Changes in moisture content are caused by evaporation, condensation or mixing with air at different moisture contents. To help determine the causes of RH changes, moisture content in outdoor and indoor air can be established from the CIBSE psychrometric chart.

The table below plots indoor and outdoor RH, temperature and moisture content for 17th May which is taken as an example:

Time	Outside % RH	Outside °C	Outside air mc*	Inside % RH	Inside °C	Inside air mc*
00.07	55.5	12.0	0.0045	41.0	16.6	0.0052
03.07	60.0	11.0	0.0050	43.5	16.0	0.0050
06.07	64.5	11.2	0.0054	46.5	15.6	0.0050
09.07	55.0	14.8	0.0063	47.5	15.8	0.0054
12.07	71.0	15.6	0.0083	58.0	15.8	0.0058
15.07	80.0	15.6	0.0089	63.0	16.0	0.0072
18.07	82.5	16.2	0.0093	65.5	16.0	0.0075
21.07	85.0	15.6	0.0096	68.5	16.4	0.0080
23.52	85.0	14.8	0.0090	70.0	16.4	0.0082

(* mc = moisture content in Kg/kg of dry air).

It shows that the relative humidity and moisture content of the inside air increased through the day in response to outside conditions while the inside air temperature remained relatively steady. Therefore changes in moisture content were predominantly responsible for changes in RH. It indicated that moisture had moved from outside to inside the building. The likely cause of such a phenomenon is a combination of air infiltration and

Fig. 7: Graph for indoor and outdoor temperature

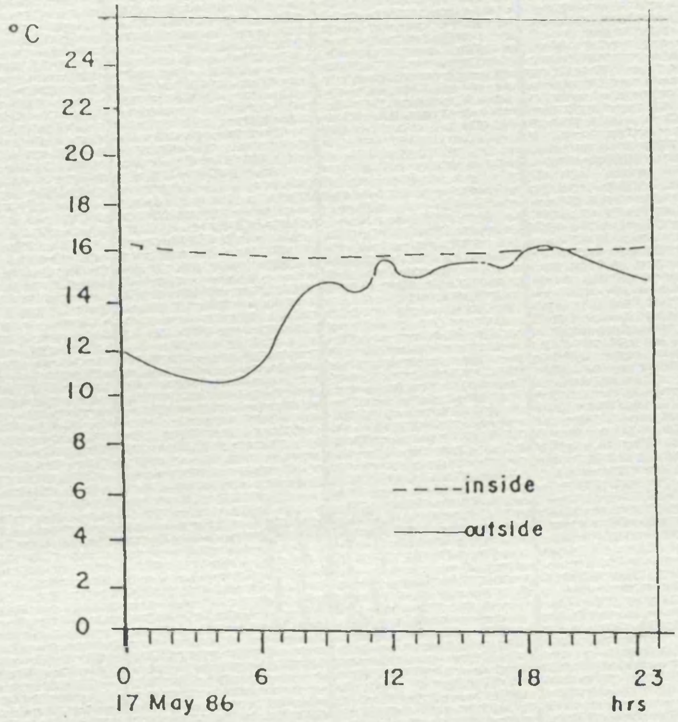
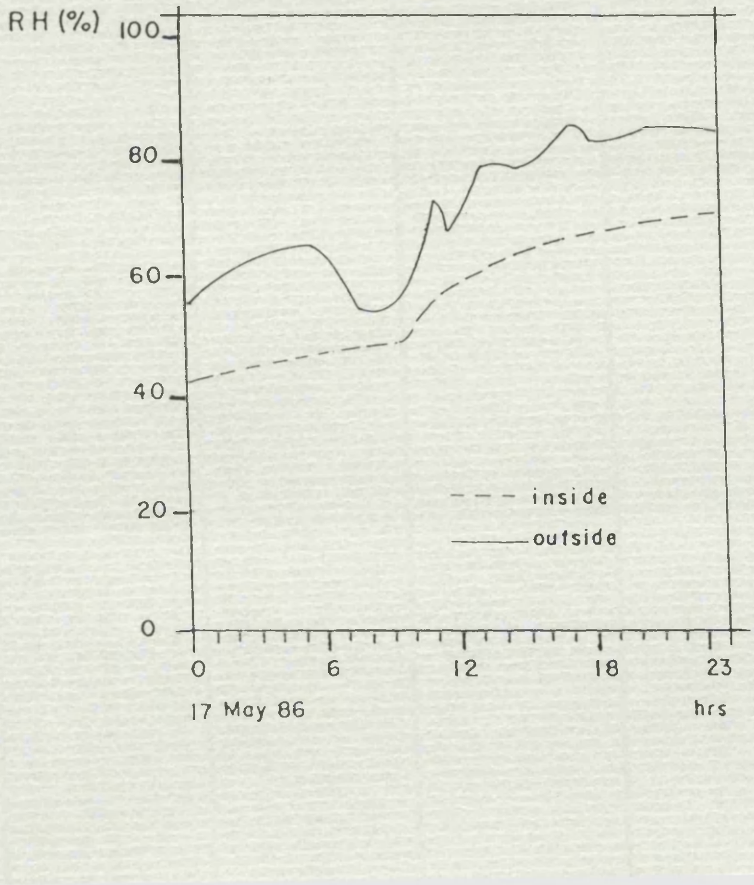


Fig. 8: Graph for indoor and outdoor RH



moisture transfer through the fabric of the building. This affected the buffering capacity of the building[9].

Other measurements of relative humidity and air temperature were carried out in smaller rooms in Somerset House, namely the Fine Rooms to determine the response rate of inside air temperature and moisture content to changes in outside conditions[10]. (The environmental performance of these rooms will be described in the next chapter). One room, the Joint Ante-Room now Gallery 4, faced south. It responded slowly to external temperature changes, in a pattern similar to that of the Great Room. The moisture content of the air in Gallery 4 and outside has been recorded (**Figure 9**). The graph of both indoor and outdoor air for the period 22nd August till 27th August shows that indoor air moisture content responded closely to outdoor conditions.

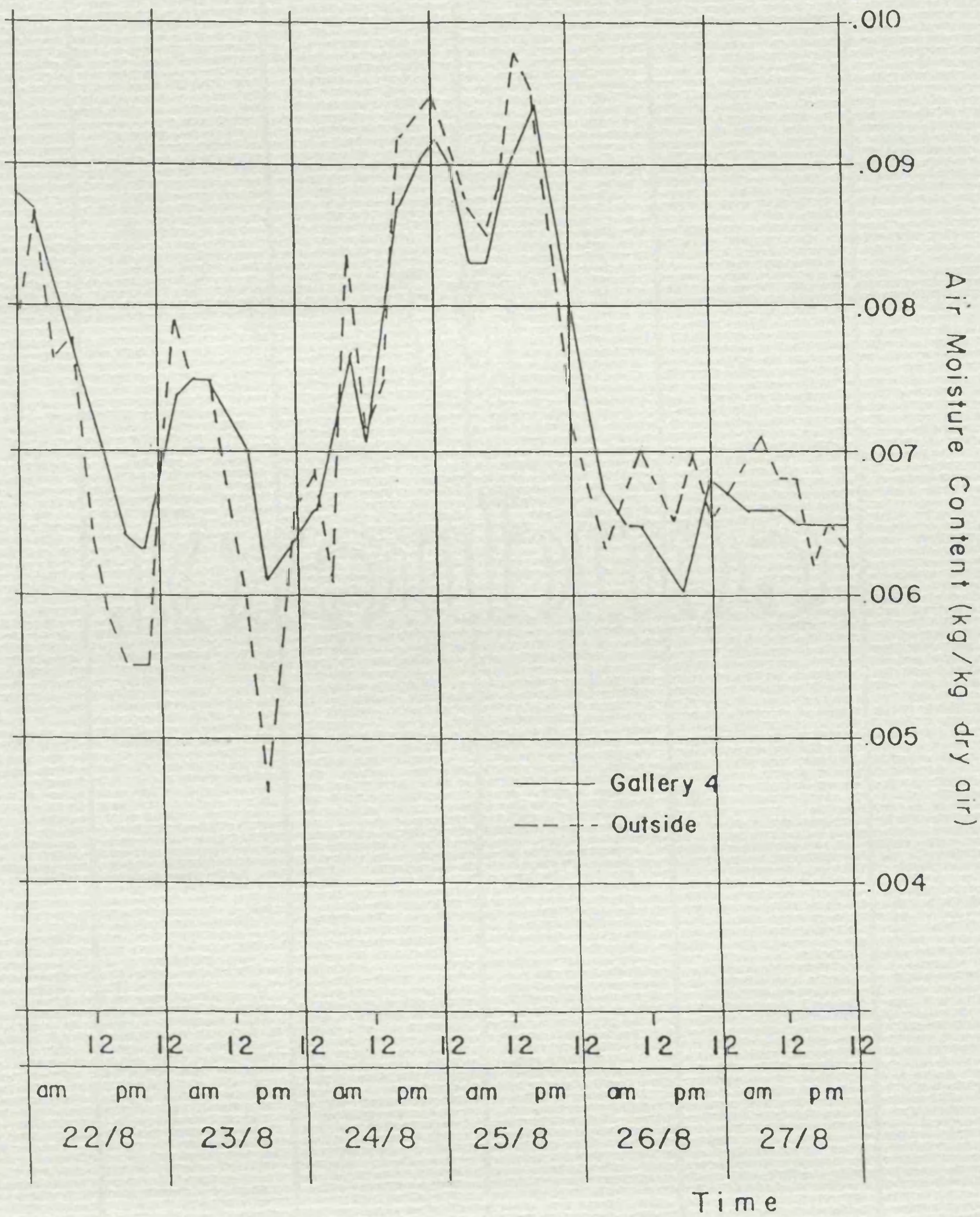
The time-lag of inside to outside air moisture content was frequently, 'as little as one hour and only once over six hours'[11]. This indicated that the building had very little buffering effect on outside relative humidity. While this may appear to contradict conventionally held views that heavy buildings act as good buffers, this may be the case when air infiltration is high.

Air Infiltration

The practical example has demonstrated that the interior of an old building responds readily to temperature and air moisture content changes in the exterior probably due to air infiltration rather than transfer through the fabric of the building, on account of the speed with which it takes place.

Low technology measures can be taken to improve climatic stability in these areas. Control of draughts can be partly rectified through detailed design and adequate weather stripping. Installing doors and where necessary draught lobbies leading from

Fig. 9: Air moisture content outside and in Gallery 4



galleries to stairwells and closing service ducts at each floor level is desirable to prevent vertical air movement. These measures should have a stabilising effect on the internal climate[12].

Sealing

Tests were carried out at Somerset House to determine what effect sealing the doors, windows and chimney would have on the internal moisture content changes. Measurements of the room, sealed and unsealed, were carried out on south-facing Gallery 4 in August and September 1986. The doors and windows were closed and the room was sealed by covering the doors, windows and the fire place were covered with polythene sheet which was taped around the edges[13]. Tests on the unsealed room (**Figure 9**) showed that the internal air moisture content followed the external moisture content closely, with little resistance to the transfer of moisture to the air in the room. Tests on the same room which was sealed (**Figure 10**) showed the internal moisture content reasonably stable, responding slowly to changes in external air moisture content. Short term changes in the external air moisture content did not affect the internal air moisture content.

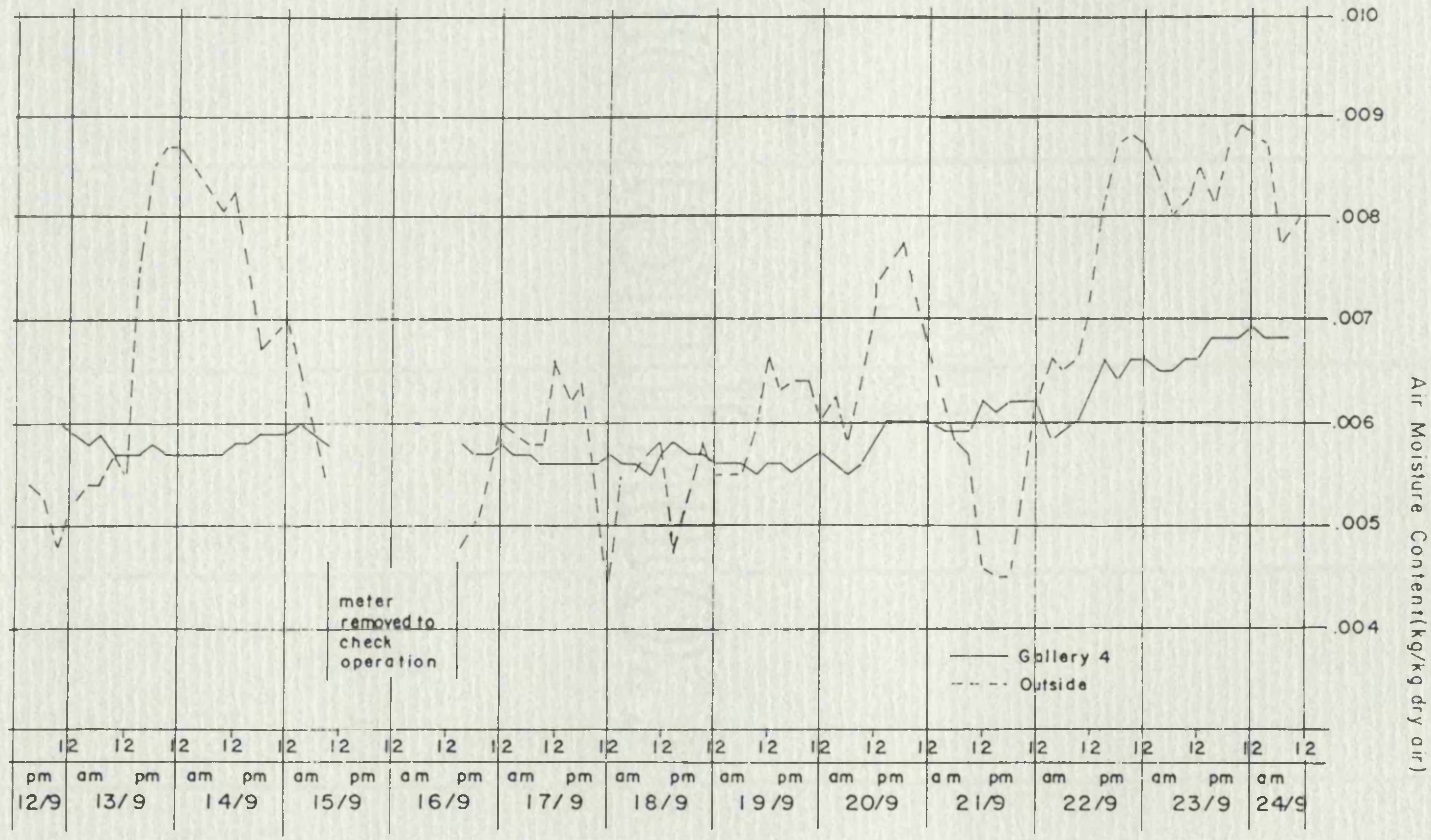
Significant differences in external air moisture content caused a gradual change in the internal air moisture content towards that of the outside.

> 'This change in the inside air moisture content takes place over a much longer period than in the case of the unsealed room and the time-lag is days rather than hours'[14].

EFFECT OF PEOPLE ON THE PASSIVE CONTROL OF THE BUILDING

While sealing a building can increase the time-lag of the building's response to external changes and improve the stability of the internal environment, it can only do so if the building is not in use. In the case of a building in use, sealing would not allow internally generated heat and moisture to escape.

Fig. 10: Air moisture content outside and in sealed Gallery 4



The presence of large numbers of people in a sealed space, their effect on the internal relative humidity and temperature and their requirement for ventilation are discussed in Chapter 5.

'Tests have indicated that ordinary walls of brick, tufa or sandstone of medium thickness....allow the passage of some 300g of water per square metre daily when not protected by a coating which renders them impermeable'[15]. This should be weighed against the fact that each person emits about 60 grammes of moisture per hour and that people are visiting museums in ever increasing numbers. Therefore the fabric of the building alone often cannot eliminate the effect of human activity which partly drives changes in indoor climatology. It is a well documented fact that, '..in rooms open to the public, (the effect of outside conditions and human activity) cannot be easily separated....'[16].

EFFECT OF THE PLAN OF ROOMS

Bearing in mind that buildings have some effect on the buffering of external conditions, the plan of a building and its rooms can help to enhance this effect. Particular attention needs to be given to the use of the rooms on the windward side of the building. Normally air flow is greatest through these rooms from which air will move through the rest of the interior. The climate in the rooms on the windward side is likely to be less stable than in any other part of the building.

Within the building itself, not all rooms are affected equally by external conditions and different rooms have a varied microclimate. The layout of the rooms and their orientation will either increase control over external conditions or mirror them closely. While the building shell provides coarse control over prevailing external conditions, with rooms on the perimeter receiving the greatest impact from the weather, the rooms located in the interior of the structure act as effective climatic buffers and promote a more stable indoor climate.

Where possible, this information should be used in deciding on the plan of the rooms within a new building or in the allocation of rooms in an existing one, so that objects are allocated the more stable parts of the building. Such an approach would promote 'passive zoning' of rooms and the allocation of space for use according to environmental needs of both objects and people.

The parts of the building found to be more environmentally stable would be used primarily to satisfy the needs of the collection, with an appropriate level of technology being applied to supplement the natural buffering capacity of the structure itself.

Exhibiting or storing objects in a room well protected from external conditions would seem to offer many advantages to the preservation of the collection [**Plate 1**]. For example, the Drawings Collection at the Courtauld Institute Galleries in Somerset House is stored in a windowless room inside storage cabinets. During the period 18th December 1990 to 4th January 1991, ambient relative humidity stabilised between, 57% and 59% RH while ambient temperature stayed between 13.4°C and 16°C (**Figures 11 amd 12**). During this period the temperature and RH in a Gallery on the perimeter of the building varied between 52% and 63% RH.

This makes control over relative humidity and temperature easier and cheaper because full advantage is taken of the buffering effect that separation from the exterior has to offer. When windows are eliminated, the need to control solar radiation and associated external heat gains and heat losses is avoided and the efficient use of energy is promoted.

It is useful to illustrate how such passive interior design might work. The outer perimeter of a museum building which is influenced predominantly by external conditions is ideally suited

Fig. 11: Ambient temperature in Drawings Collection store room

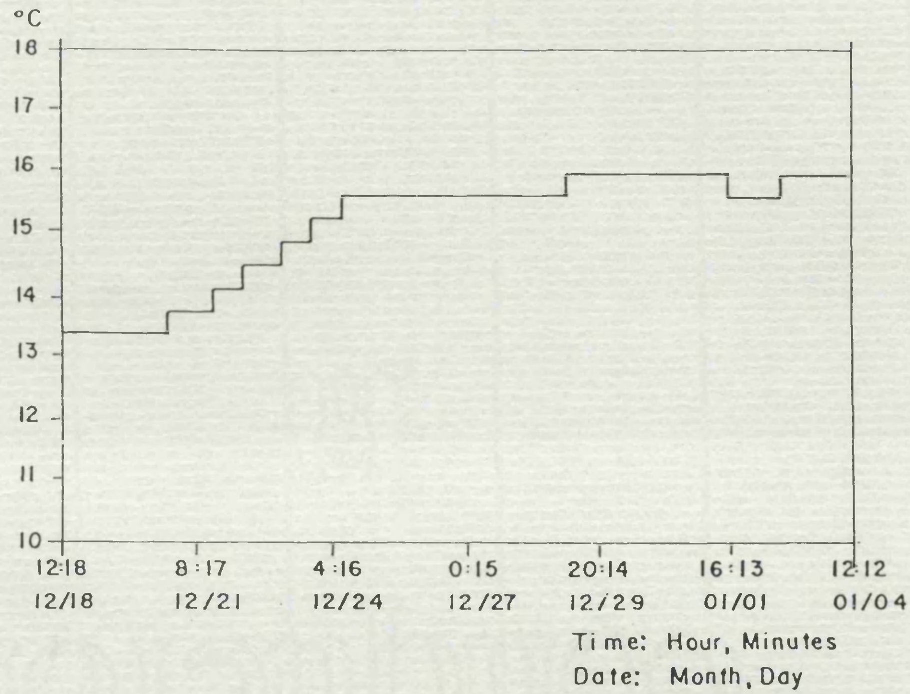
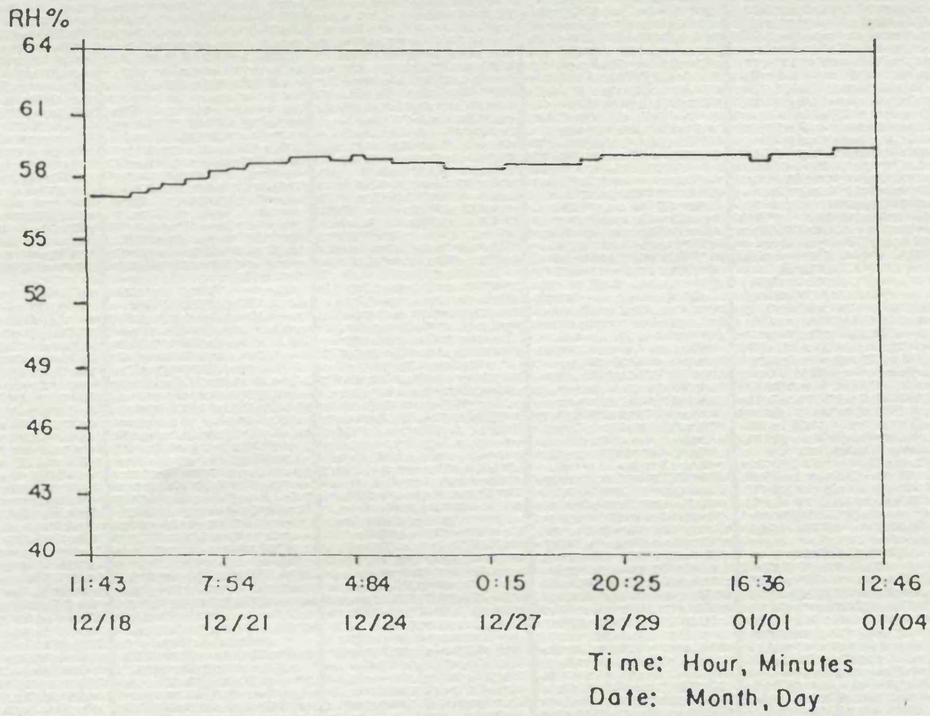


Fig. 12: Ambient RH in Drawings Collection store room



for use as offices, souvenir shop and cafe or restaurant area. It would typically require heating and cooling controlled across the human thermal comfort range. It would also provide natural light and warmth for human occupation. Robust objects from the collection could also be displayed in areas with similar environmental characteristics. For example, stone sculpture could be displayed in a daylit space such as a conservatory, atrium or lobby in human thermal comfort conditions.

USE OF SPACE IN ROOMS

> 'Interactions between masonry surface and atmospheric environment can cause local variations of air temperature or moisture content in the proximity of surfaces'[17].

A recognised but as yet little used criterion for deciding the location of objects in exhibition spaces and storage areas, is the local climatic variations within the rooms themselves. For example, the location of a climatically sensitive object such as a painting on wood panels needs to be carefully selected. It should be hung on an internal wall to reduce the effect of climatic differentials between the front and the back of the painting. These differentials would be greater if the painting were hung on an external wall.

Data from continuous monitoring and in particular from environmental surveys should be used routinely to provide the evidence needed to build a profile of the thermal characteristics of different locations within a building[18].

There are signs that surveys are starting to be carried out with the aim of drawing up environmental profiles of rooms whih are used to exhibit objects[19].

USE OF DISPLAY CASES

In recent years museums have begun to look beyond dependence on mechanical and electrical systems to the application of control over the microenvironment. Increasing use is being made of passive methods of localised protection for museum objects on display and storage[20,21].

Display cases or storage boxes have been used to provide environmental protection for objects on exhibition for some years. There are a number of compelling reasons which include:

i. the inability of the building to act as an effective buffer in stabilising weather conditions
ii. the difficulty of locating objects within areas in the building which have a stable environment
iii. the inability of the environmental services within the building to provide the level of control required by the objects
iv. the running cost of providing a constant fine level of control for a small group of objects in the collection
v. the instability of some materials in an environment which is not strictly controlled
vi. to segregate objects and people within the same space
vii. to provide protection against short-term fluctuations caused by an influx of humans into a space
viii to protect objects against the effects of urban pollution as long as the materials of the display case have been tested for off-gassing.

The simplest method of providing localised environmental control is to isolate an object or group of objects inside a display case or storage box to help buffer ambient conditions[22].

Experiments conducted some years ago, established that a well-made display case can go through 1 air-change per day[23]. More recent work at the Canadian Conservation Institute has indicated that this has decreased to 1 air-change every 10 days[24].

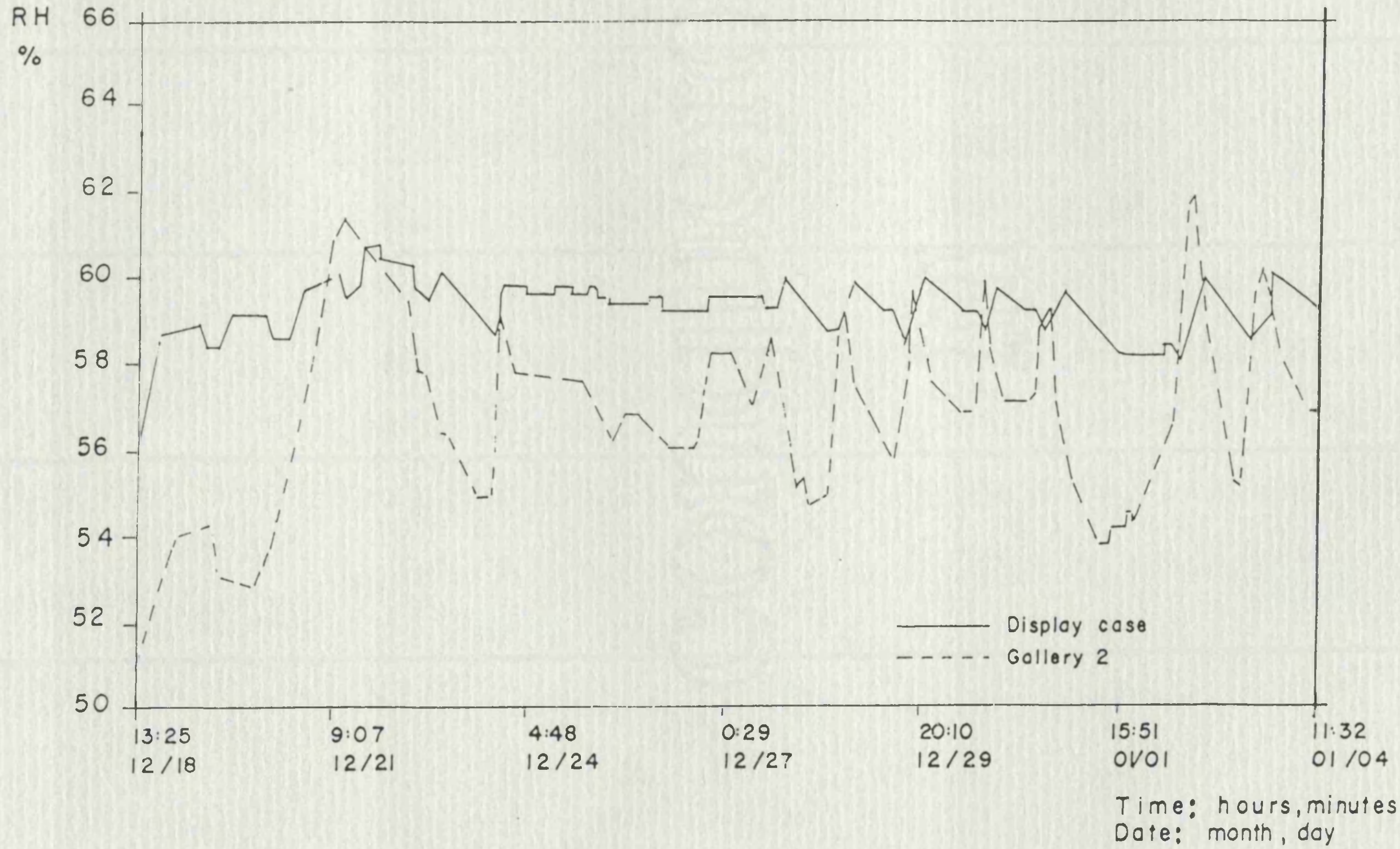
The display case in particular therefore provides more than just a physical barrier against theft or damage. A well-designed and well-constructed display case acts also to stabilise the climate immediately around objects because relative humidity changes inside the case lag behind those in the air outside it[25]. For example, the relative humidity within one display case in Gallery 2 in the Courtauld Institute Galleries [**Plate 2**] was monitored at the same time as ambient relative humidity between the 18th December 1990 and 4th January 1991 (**Figure 13**). The graphs show that the range of RH fluctuation inside the case was considerably less than that in the room itself.

Humidity-sensitive objects may require further intervention to control the climate inside display cases. Microclimates can be created inside display cases by using the desiccant, silica gel to raise, lower or stabilise relative humidity independently of ambient temperature. Case studies have reported the use of a variety of methods for controlling the climate within museum display cases. They have been used with great success especially in situations where the building and the environmental systems cannot provide more than broad band control over ambient conditions.

They have been used to protect objects from a fluctuating environment caused by the effect of external influences on a 'thin' building for example, the Sainsbury Centre for Visual Arts at the University of East Anglia[26], and by the effect of internal fluctuations caused by large numbers of visitors in a 'sealed' building, for example, the Courtauld Institute Galleries at Somerset House which will be discussed in the next chapter.

Passive local control has several advantages over active control of large volumes of air within whole buildings or suites of rooms.

Fig. 13: Graph of RH vs time for Gallery 2 and display case



The structure of an older building is not affected by the use of microclimates within display cases or storage boxes; new buildings can be designed to provide thermal comfort conditions for visitors within galleries and fine control over relative humidity and temperature around the object inside the display case. Because microclimates within cases often use passive systems, they do not consume energy in use and they cannot break down. They drift gradually towards ambient conditions as a result of air leakage through cracks in the joints of the case. A gradual change of climatic conditions is preferable for objects to a sudden failure of a mechanical and electrical system that can cause rapid changes to environmental conditions which are potentially damaging to the object. Microclimates provide the fine level of control, within $\pm$ 2% relative humidity which is required by some humidity-sensitive objects while air-conditioning systems can only provide this level of tight control at great running and maintenance costs.

CONCLUSION

While the use of passive control methods offered by the buffering capacity of the building will help improve the stability of the internal climate, this will not be enough to provide the tight levels of humidity control required by some of the more sensitive museum objects such as archaeological metalwork and ethnographic objects. The use of microclimatically controlled display cases for such materials should provide the tight control that is required.

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CHAPTER 4

ACTIVE CONTROL OF THE MUSEUM ENVIRONMENT

AIR-CONDITIONING OF MUSEUMS AND GALLERIES

Traditionally, the preferred solution of museums to problems with internal climatic instability and indoor air quality has been the use of air-conditioning. Fluctuations are unacceptable in the museum environment because of the risks they pose to the physical integrity of the objects on display and in storage (see Chapter 2).

> 'The complete answer to climate control is a central unit distributing fully conditioned air through ducts to all parts of the (museum) building or at least to all exhibition and store rooms....New museums should give it a very high priority'[1].

Definition of the term air-conditioning

Often a different interpretation is given to the term 'air-conditioning' by building services engineers and museum staff. It is a term usually used by building services engineers when cooling and dehumidification is intended. Therefore air-conditioning is always associated with refrigeration, but it does not necessarily include full control over relative humidity[2]. On the other hand, 'air- conditioning' may simply be understood by museums as a ducted system of conditioned air, but one which should attain full control of relative humidity in zones where the collection is housed.

In the context of this report, the term 'full' air-conditioning describes an arrangement of equipment that is capable of filtering, heating and cooling, humidifying and dehumidifying and distributing air throughout a space, within the limits imposed by the design specification.

'Central' air-conditioning involves the use of one energy centre, comprising the boiler which produces heat, and the water chiller and cooling tower which provide cooling.

Conditioned air is delivered through ductwork from one or more air handling units, to various parts of a building. An alternative approach would be to use 'decentralised' air conditioning which employs 'packaged' systems for different zones in a building.

OTHER MECHANICAL MEANS OF ENVRIRONMENTAL CONTROL

Mechanical and electrical means of solving environmental problems are so commonplace that many museums consider actively conditioning air as the first and only method of achieving climatic stability within the museum environment. Indeed full air conditioning in museums provides a complete solution because it cleans and delivers air as well as controlling temperature and relative humidity.

However, there is a wide range of other mechanical/ electrical methods of environmental control from which to choose in order to achieve a fine level of control. Some, like air-conditioning, are more suited to the control of large volumes of air within rooms or whole buildings, while others such as the use of transportable humidifiers and dehumidifiers, can only be effectively applied to small localised volumes of air.

In order to get round the shortage of funds for capital projects and the difficulties of accommodating machinery within buildings originally designed for other uses [**Plate 3**], measures which fall short of full air-conditioning have been installed. A random pick of mechanical installations in museums will reveal inadequacy in their design and operation from the point of view of collection needs.

Although equipment may be installed with the intention of helping to preserve museum objects, it is often so closely programmed to human needs that in the worst cases, it shuts down shortly before closing time and restarts shortly before the first members of staff arrive in the morning. The system thus sets up its own cycle of climatic change, which it was originally intended it should eliminate.

If a mechanical system of climate control is installed to benefit the collection, it needs to run continuously and not only during the hours that the museum is open to visitors.

Many museums use portable humidifiers and dehumidifiers in order to establish some control over ambient relative humidity [Plate 2]. However the integral humidistats of such equipment are often simple band-switching controllers. Relative humidity within a space has to drop below the set minimum and rise above the set maximum for the equipment to be switched on or off. Often humidifiers and dehumidifiers are found to be operating simultaneously within the same space. Furthermore, this equipment can only circulate air in its immediate vicinity, so that when the museum is closed and without the presence of visitors to help move the air around, control over ambient relative humidity is uneven throughout the space[3].

Such experiences have led to an almost fatalistic consensus of opinion within museums that mechanical systems of climate control never perform in the way they had been originally intended or that relative humidity control, so important to the preservation of museum collection, can only be achieved at a great cost. It would therefore be appropriate to outline the benefits and disadvantages of air-conditioning systems.

BENEFITS

Environmental Control

Air-conditioning in museums is required to maintain constant conditions for objects by counteracting the causes of environmental instability due to external and internal heat and moisture gains and losses. It becomes indispensible if the museum building is badly insulated, if there are large areas of unshaded glazing, insufficient controlled ventilation, too many heat producing light sources, space heating at high operating temperatures and large variations in occupancy.

When the lighting and heating systems are switched off and when there are no people present, sensible and latent heat gains disappear and the temperature drops. A rise in air temperature inside a building produces a reduction in the relative humidity of the air. Conversely, a drop in temperature causes relative humidity in the air to rise again. The rise and fall in temperature associated with heat gains, causes cyclic changes in relative humidity. In specifying tolerance ranges for relative humidity and temperature, museums often request that the band of fluctuation should be as narrow as possible. This is because when museum objects such as archaeological metalwork, start to decay as a result of adverse environmental conditions, the process tends to continue even when climatic conditions improve. However, this tight specification has often to be relaxed because the air conditioning system cannot achieve the accuracy of control that is required. For example, it is difficult to control to 1% RH when it is almost impossible to measure to 1% RH.

The following specification of the conditions that an air-conditioning system should maintain for a mixed museum collection, represents the compromise that was arrived at by the Museums and Palaces Group of the Property Services Agency[4] which, until 1989 controlled the design and maintenance of environmental systems in national museums and galleries in the United Kingdom:

Temperature	20ºC ± 1ºC
Relative Humidity	50% RH ± 4% RH
Maximum sulphur dioxide levels	0.0035 ppm
Particle Filtration	85% Eurovent 4/5

Although this specification remains current, the control of other pollutants such as the nitrogen oxides and ozone have now also to be added.

DISADVANTAGES

The decision to install air-conditioning has to weigh practical considerations as well as the needs of the museum collection.

Space

The installation of air-conditioning requires capital expenditure and the availability of adequate space for the necessary plant and ductwork. There is no published guide to the space required by air-conditioning plant as a percentage of the floor area in museums. It probably lies somewhere between the 9% estimated for office buildings and the 15% estimated for a small, but comprehensively serviced hospital[5]. 10%-15% of the floor area in the Victoria & Albert Museum in London has been suggested as a rough guide to the space occupied by air-conditioning equipment[6].

Costs

Ongoing operational costs for running and maintaining the system also need to be considered before a decision is made in favour of air-conditioning. A research project undertaken by BSRIA revealed that in the third quarter of 1989, maintenance of air-conditioning systems in office buildings cost 2.5 times more than maintenance of heating systems. Although this is based on a small sample, it represents a recent example from which an idea of the cost to museums of air-conditioning might be deduced[7].

Maintenance

Lack of maintenance of the air conditioning system was found to be a contributory factor in the outbreak of Legionnaires' Disease at the Science Museum in London some years ago. Lack of maintenance can also have serious direct consequences on the collection. Climate control equipment can break down causing rapid RH fluctuations which do not occur in passively controlled buildings.

Controls can go out of calibration and filters can clog up, thereby causing a pressure drop in the air as it goes through the filter. A clogged filter can also shed minute particles of dirt into ducts. These are then carried in the air supply into the internal environment and can be deposited on objects in the exhibition space.

Installation

The installation of air-conditioning is only reasonably straightforward in new museum buildings or in new extensions to existing ones. Over the last year, the best publicised major new museum developments have been The Sainsbury Wing of the National Gallery and the Sackler Galleries in the Royal Academy. In reality, out of approximately 2000 museums in the United Kingdom, only a few are housed in purpose-built buildings where provision for the installation of appropriate environmental services had been considered from the start of the project.

Even buildings which had originally been constructed for museum use, for example the Horniman Museum in south east London, built in 1901 are no longer adequately fulfilling their function as museums. Among the reasons for this, are growing awareness of the need to expand the services required to sustain a modern museum (see Chapter 1), and frequently, lack of maintenance to the building fabric and services.

The fact that many museum collections are housed in refurbished premises makes the task of introducing central mechanical and electrical methods of climate control virtually impossible. Often space cannot be found for the installation of air handling units, other plant and related ductwork. One alternative is the use of a 'packaged' air-conditioning unit. This consists of an air handling component, which can contain humidifiers and the refrigeration plant in one cabinet.

A situation familiar to museums are installations of climate control equipment within historic and sometimes listed buildings. 'Split packaged air-conditioning' in which the air handling unit and the refrigeration plant are located in different places though they remain connected by the refrigerant pipework, can provide more flexibility in finding space to accomodate the required equipment. In spite of this, it can be very difficult to thread complex new services such as lagged pipework pumping coolant around the system, through a sensitive historic structure [**Plate 4**] especially when floor strengthening is required.

Legislation which protects listed buildings can also prevent the required changes to the fabric to introduce these services. There are numerous museum collections whic are housed in important historic buildings. 57% of the museums sampled in a recent survey of museums in the United Kingdom occupy a listed building[8].

Fabric

Very few museums and galleries especially those housed in old buildings, are fully air-conditioned. The same survey mentioned above also revealed that most museum buildings in the United Kingdom were constructed between 1850 and 1899[9]. The installation of air-conditioning in an existing building results in humidification during the winter period. This can cause increased stress in the building fabric. Concern exists that a controlled environment for objects which involves humidity control, may adversely affect the fabric of a historic building. If the interior is humidified, thereby raising the vapour pressure inside the building, interstitial condensation can occur when there is a temperature difference between inside and outside for certain external building fabric constructions.

CONCLUSION

Most small museums rely on transportable humidifiers and dehumidifiers to control the environment in spaces where objects are housed. Large museums which are housed in recently constructed buildings, generally plan for the installation of centralised air-conditioning systems, while museums housed in large old buildings are often obliged because of the lack of space, to install control equipment wherever room can be found. This means that localised control is the best that can be achieved. The overwhelming majority of museums do not rely only on passive control of the internal environment in spaces in which objects are housed.

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CHAPTER 5

THE COURTAULD INSTITUTE GALLERIES: A CASE STUDY

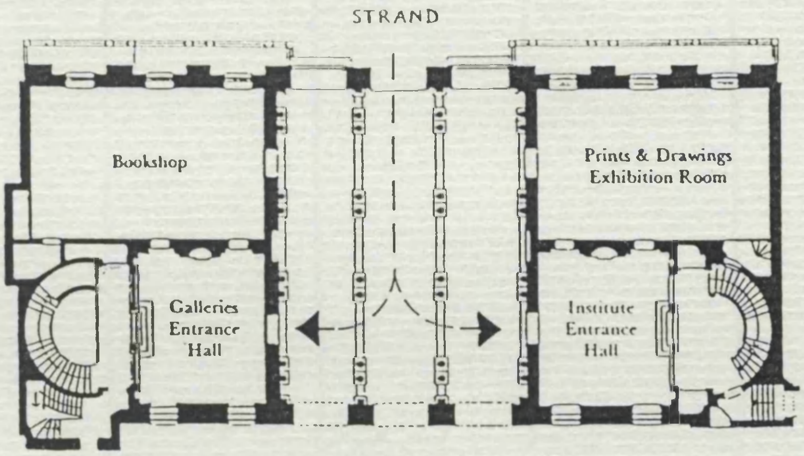
The last three chapters have compared the requirements of objects and people in the museum environment and the options for active and passive control that can be used to meet these needs. The added difficulties imposed by an existing building in resolving these issues satisfactorily, was also highlighted. This chapter illustrates these issues through the discussion of a case-study in which all these problems manifested themselves.

THE COURTAULD INSTITUTE GALLERIES

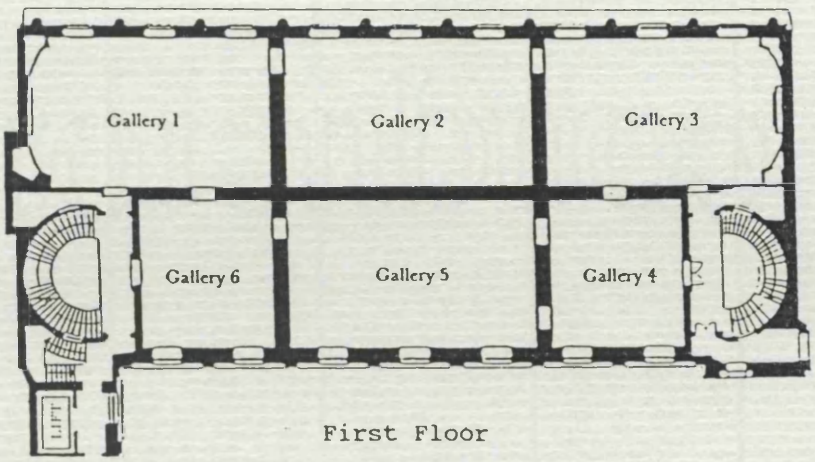
The Courtauld Institute Galleries at Somerset House is examined in detail in this chapter because they illustrate how complex is the problem of reconciling 'the physical demands of (putting an existing building to)...new uses and the physical demands imposed by the historic building'[1]. The Galleries demonstrate the difficulties of providing tight environmental controls for the contents of a building which is itself of outstanding architectural significance. The case-study confirms what was suggested in the last chapter, that environmental stability cannot be achieved exclusively by passive controls by using the thermal mass and hygroscopic properties of the building fabric, and that instability is worse in the summer than in winter, especially during the time when the space is occupied.

The Courtauld Institute Galleries are situated in a sequence of historic rooms (**Figure 1**) in the north block of Somerset House overlooking the Strand in London [**Plate 5**]. The collection displayed in these rooms contains among the best examples of easel paintings and panel paintings from the 15th to the 20th century, including paintings by Rubens, Tiepolo, the Impressionists, Modigliani and Nicholson. While these paintings are unique in their artistic value they are, in common with similar museum materials, subject to deterioration as a result of unstable environmental conditions.

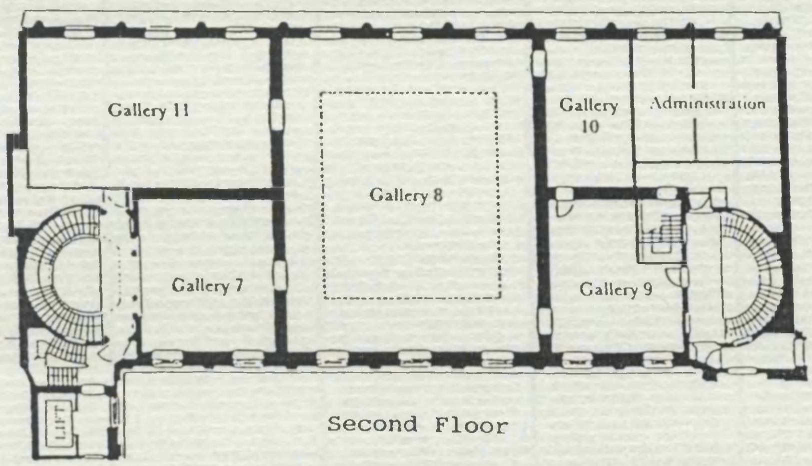
Fig. 1: Plan of the Courtauld Institute Galleries



Ground Floor



First Floor



Second Floor

Until the move to Somerset House, the Courtauld Institute of Art had been housed in increasingly cramped conditions on two separate sites. The Institute campaigned to be given new premises and in 1984, the Somerset House Act enabled the University of London, of which the Institute is a part, to lease the north block. The project was to cost £10 million, of which £6 million had to be raised from public donation[1].

THE CLIENT'S BRIEF

In planning the refurbishment of the building and the conversion of the Fine Rooms into an art gallery, careful consideration had to be given to achieving appropriate climatic conditions before the collection of paintings was put on display.

Devising a solution to control the climate within the Fine Rooms illustrates clearly the difficulties of fitting technically demanding uses within a historic building. As a Grade 1 listed building, any proposed alterations to the fabric would require local authority planning permission and listed building consent from English Heritage, the body empowered by statute to protect listed buildings. A feasibility study on whether the Courtauld Institute of Art should move into Somerset House had identified the difficulties presented by the building and the use for which it was intended. An appropriate environment for pictures had to be created, while avoiding 'too moist an atmosphere (within the building), at times when the temperature outside is very low, (which) can give rise to condensation'[2]. It was clear therefore that when the Courtauld Institute of Art decided that Somerset House would provide suitable gallery space for its collection, it also took on responsibility for the preservation of an 18th Century Grade 1 listed building which was as demanding in its environmental needs as the collection which was to be housed within it.

The Courtauld Institute specified the following environmental conditions for its collection:

Temperature (winter minimum)	16°C
Temperature (winter minimum: night)	13°C
Relative Humidity (minimum)	45%-50%
Relative Humidity (maximum)	70%

These conditions represented a compromise between the ideal requirements for the collection and the need to preserve the fabric of the building. Furthermore, the Courtauld Institute also required that for the conservation of objects, the building should be sealed in order to minimise air infiltration. A feasibility study of the services at Somerset House concluded that the fresh air requirement would have to be provided by mechanical means and that the existing system of hot water radiators should be re-used wherever possible.

English Heritage expressed concern that even the minimum relative humidity level of 45% which the Courtauld Institute required for its collection could cause surface or interstitial condensation during the winter when there was very low external temperature because of the nature of the construction of the walls. A number of studies were therefore carried out to assess the risk of interstitial condensation. An 'Environmental Appraisal' prepared by Ove Arup and Partners concluded that at 18°C or 19°C and at 50% RH there appeared to be the possibility of condensation within the thickness of the external brick/stone walls but that it was unlikely to occur in the cavity between the inner face of the external walls and the plasterwork[3]. A risk assessment based on computer predictions of the likelihood of surface or interstitial condensation at external temperatures of -1°C, -5°C and -10°C concluded that a risk existed if the external temperature dropped to between -1°C and -5°C, if the walls were made entirely of stone and if the internal temperature was above 15°C.

According to records from the Meteorological Office, external temperatures dropped to between -1°C and -5°C between 1 and 3 hours per month only in the previous 10 years and that in the case of Somerset House, it was extremely unlikely that stone only would have been used in the construction. Therefore although the internal temperature could not be kept as low as 15°C because of human thermal comfort needs, the risk of condensation at these temperature was low[4]. This highlights a problem common to many old buildings using sophisticated predictive techniques, that the biggest unknown is the construction.

PROPOSED SOLUTIONS

In deciding upon the approach to controlling the internal environment within the Galleries in Somerset House, the Courtauld Institute was faced with a choice between two different solutions, either a mechanical and electrical approach or a passive approach to achieving climate control.

Active Control using Mechanical and Electrical Plant

The option proposed by the design team relied on mechanical and electrical control of the internal climate. In devising the scheme, the consulting engineers took on board the condensation risk studies that had been previously commissioned. They were concerned that the need to introduce humidification to achieve the minimum relative humidity level of 45% for the collection during the winter heating period, could endanger the building fabric when the external temperature was low. The decisions which had been made to reduce the risk of exposure of the building fabric to surface and interstitial condensation included double glazing (to avoid condensation on windows in winter conditions), foil backed coverings to the internal surfaces of the external envelope (to reduce the risk of interstitial condensation) and sealing the building (to reduce the ingress of dust)[5].

The design team also considered the internal factors that would affect environmental conditions: the number of visitors estimated at a maximum of 500, and the effect of lighting and heating in winter. Solar heat gains in the summer would have a similar effect to space heating in winter, while the other factors would stay the same. The design team concluded that 'this necessitated the introduction of a certain amount of air into the building by either natural or mechanical means' and that 'cooling for control and dehumidification' would be required[5]. This scheme broadly 'satisfied the various aspects of the brief'. These included safeguarding the building fabric and the thermal comfort requirements of the occupants. It did not give particular emphasis to the conditions required by the paintings that would be on permanent display in the Galleries. The clients ultimately decided against the scheme on the grounds of very high cost and the physical alterations that the installation of control equipment might inflict on the building.

Passive Control with Local Humidification

The option proposed by the Courtauld Institute, suggested a passive approach to the control of ambient relative humidity supplemented by heating and localised humidification. The proposal relied on the building acting 'as a 'sponge' a buffer which considerably modified the environmental conditions'[5]. The controlled response to external relative humidity and temperature conditions given by a sealed room in Somerset House as opposed to when it was unsealed, was put forward as evidence of the buffering effect of the building fabric. The scheme suggested that 'relative humidity could be kept at around 50%' provided that double glazing was installed, windows sealed and minimum natural ventilation was used by keeping external doors shut[5]. The mass of the building would be used to buffer external conditions. A conventional hot water central heating system would be installed to give thermal comfort conditions to occupants during the winter. Transportable humidifiers would be on standby for use during the time the heating system was in operation. The main advantages of this proposal were low cost, minimum physical interference with the fabric of the building while emphasising the achievement of appropriate conditions for the collection.

However, this scheme did not reconcile the differences between the environmental conditions required by the collection and their effect on the building. The scheme proposed that a stable internal relative humidity would be maintained for the collection by the building fabric freely absorbing moisture from the air. Concern was expressed that if the building were not sealed, water vapour passing into the fabric could cause surface and interstitial condensation when the walls cooled in winter. However, if vapour barriers were placed on the internal surface of the external envelope to avoid the risk of interstitial condensation, the capacity of the building to act as a 'sponge' to control ambient relative humidity for the paintings would be reduced. Furthermore, by sealing the building and providing only minimum ventilation, this scheme failed to consider the influence normal use of the space would have on the visitors to the Galleries or of the effect of people on the stability of the internal climate. Early tests that had been carried out on the response of some of the rooms to external relative humidity and temperature, and the effect of sealing one of the rooms in Somerset House, have been discussed in Chapter 4. However, the tests on which this scheme was based, had been done while the room was unoccupied.

The Preferred Solution

The doubts raised by the difficulty of reconciling the technically demanding use of the galleries with the difficulties imposed by a historic building were compounded by the cost of the scheme which recommended active control compared to the scheme which advised passive control, at a time when the Courtauld Institute was unsure that it could raise the capital required to cover the cost of the Gallery Project. A decision was therefore made in favour of the low technology scheme. Concern had been expressed throughout the planning stage about the possible damage to the building fabric by condensation in the winter and risk assessments had been carried out. The problems that the occupants and the contents of the building would encounter in the summer were not properly understood and therefore a thorough evaluation of this element of the scheme had not been done.

In accordance with the decision to adopt this scheme, a proposal for the mechanical and electrical services was drawn up. The windows in the galleries were to be double glazed and sealed [Plate 6], ventilation would be achieved by natural infiltration, the maximum number of people in the building at any one time was set at 500, temperature was to be based on a minimum of 16°C during the day and possibly lower at night, and relative humidity was to be maintained at 50% ± 5%. These conditions closely match those outlined in the client's brief. The Institute was to specify, provide and maintain transportable humidifiers to control relative humidity principally in the winter. Everything had to be done to minimise the risk to the fabric of the building and all work had to comply with any statutory requirements[6].

ENVIRONMENTAL CONDITIONS AFTER THE REFURBISHMENT

The day the Galleries opened to the public, ambient relative humidity in Gallery 5, which drew the most visitors because of the popularity of the Impressionist paintings exhibited there, rose from 56% to 76% in approximately 7 hours. The temperature rose from 20°C to 25°C during the same period of time and the number of visitors on the first day was 1727. Similar environmental conditions and large crowds of visitors were a pattern that was to be repeated in the following days and weeks. A month after the opening of the Galleries, the conservators responsible for the collection wrote,

> 'In the long term paintings exposed to such conditions will start to take on distortions. Panel paintings will develop more pronounced permanent warps and canvas paintings will form bulges and ripples. It is possible that some of the panel paintings will lose paint through flaking. Our relatively well preserved Impressionist Collection will look significantly altered after ten years of such exposure..'[7].

To understand why unacceptable environmental conditions occurred after the opening of the Galleries on 15th June 1990 in spite of the preparations that had been made, recording thermohygrograph charts for Gallery 5 for the period between the end of April and the end of July have been examined in detail. From the week beginning the 30th April until the week beginning 11th June, (**Figures 2 and 3**) relative humidity stayed within the band of 47% and 60%, that is within the Courtauld Institute's broad specification. Temperature was stable, staying within the band 18°C to 23.5°C throughout this period. Stable conditions were maintained by operating humidifiers and by keeping the doors leading to the galleries closed. Although the central heating system was turned on till late May, air temperature was maintained with little assistance from the radiators[8].

The Effect of Visitors on the Internal Climate of the Galleries

In the first 10 days of its opening, the Galleries received almost 17,500 visitors with a maximum daily throughput of 2555 on Wednesday 27th June (**Figure 4**). Visitor numbers were very high around the opening of the Galleries but they gradually stabilised between 850 and 1275 per day by the end of July. After an inital peak, visitor numbers on Sundays (a half-day opening) also levelled between just under 500 to 850 per day. Data on the number of visitors present at any one time in the Galleries is not available. However, it is likely that the design specification of a maximum of 500 people was exceeded some of the time. The figures averaged 1100 visitors per day during July.

Fig. 2: Weekly minimum/maximum temperature in Gallery 5

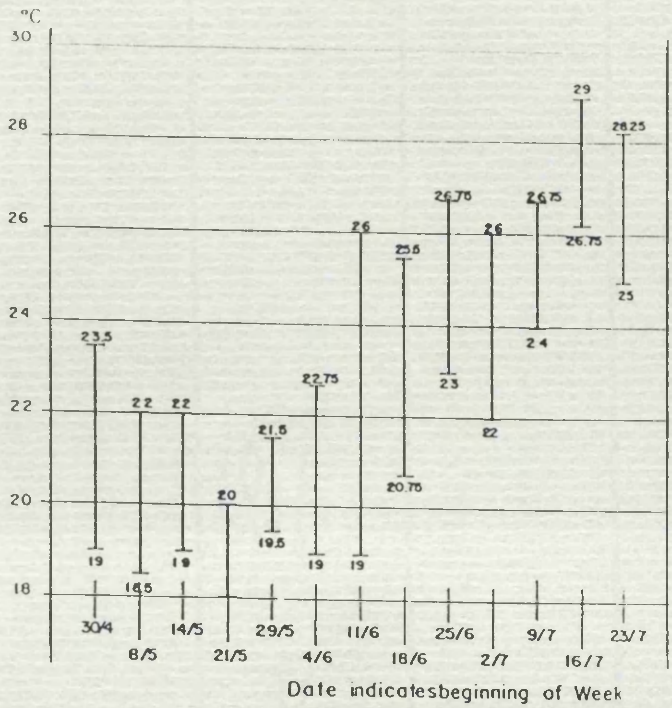


Fig. 3: Weekly minimum/maximum RH in Gallery 5

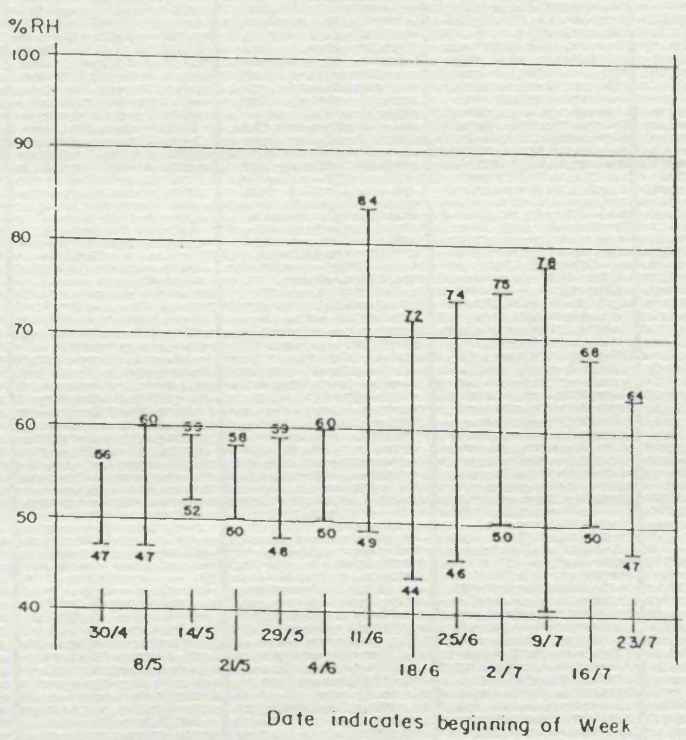
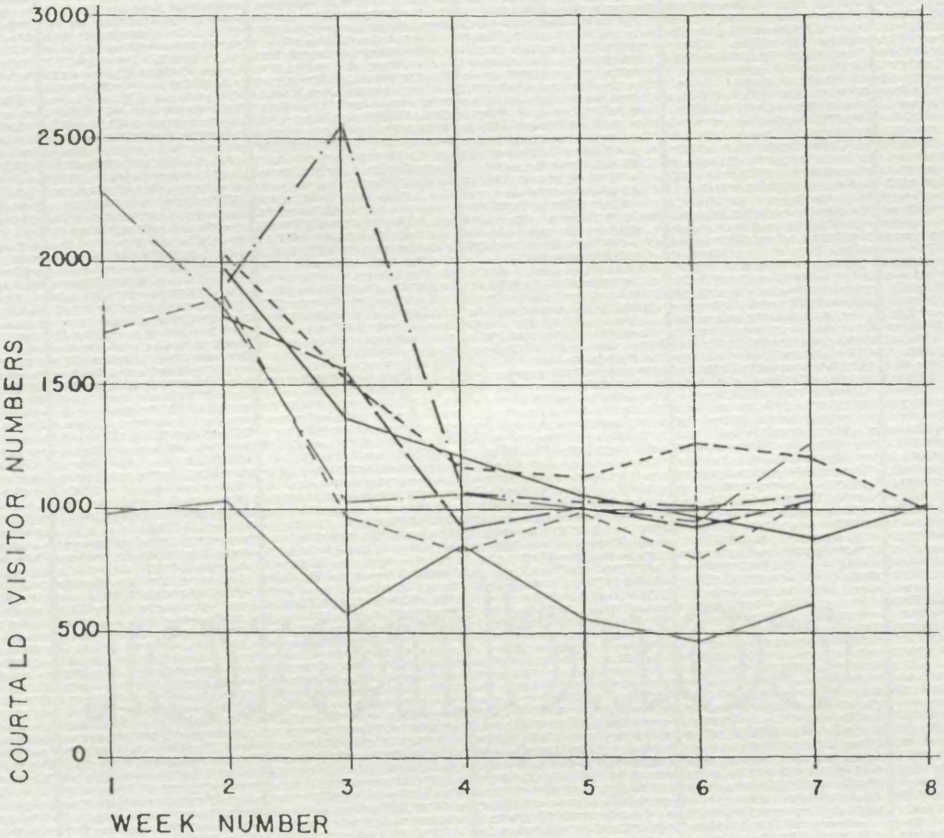


Fig. 4: Daily total visitor numbers to Courtauld Institute Galleries between 15th June and 31st July 1990



	1 (11/6)	2 (18/6)	3 (25/6)	4 (2/7)	5 (9/7)	6 (16/7)	7 (23/7)	8 (30/7)
Monday		1971	1387	1209	1054	1000	900	1025
Tuesday		2025	1541	1174	1145	1282	1214	1016
Wednesday		1915	2555	1051	1044	1003	1061	
Thursday		1786	1574	943	1051	949	1050	
Friday	1727	1859	984	848	996	810	1050	
Saturday	2281	1819	1033	1053	1004	952	1265	
Sunday	987	1045	588	851	562	479	626	

The opening of the Galleries coincided with warm summer weather. The Meteorological Office's records for the London Weather Centre in Holborn, close to Somerset House show that external temperatures during the week starting 11th June rose from a minimum 10.1°C at 5.00am on Tuesday 12th June to a maximum of 21.9°C at 1.00pm on Sunday 17th June. The respective values for external relative humidity were 79% and 38% (**Figure 5**)[9]. In contrast to the climatic stability experienced inside the Galleries during the first part of the week starting 11th June, except Tuesday when a reception was held, relative humidity fluctuated between 49% and 85% and temperature rose from 19°C to 26°C inside Gallery 5 during the latter half of the week (**Figure 6**). The same trend continued till the end of July, the date until which records have been examined. The minima over several weeks rose from 19°C to 26°C by the middle of July, and the maxima rose from 20°C to 29°C. Relative humidity dropped slightly below the weekly minimum that had been recorded before the opening of the Galleries. However the band of RH fluctuation in any one week was as much as 37%.

Fans located in humidifiers were used to create some air movement and hence increase evaporative cooling of the attendants and visitors. However, moisture which evaporated from people into the air contributed to a steady rise in relative humidity in the galleries during the day. These high water vapour inputs from large numbers of people were not present, neither were they simulated or allowed for, in the tests on which the decision to seal the Galleries was based. The effect of visitors on a sealed environment with reduced ventilation was dramatic. The large number of visitors on the opening weekend caused an increase in relative humidity of 26% within 6 hours on both Saturday 16th June and Sunday 17th June. Relative humidity on each occasion returned to the average previously maintained by the following morning. This pattern was characteristic of the busier rooms on many occasions (**Figure 7**).

Figs. 5-6: Ambient readings starting at 0 hours on 11th June 1990 (unbroken line = RH; broken line = temperature)

Fig. 5: Meteorological Office (Holborm Weather Centre)

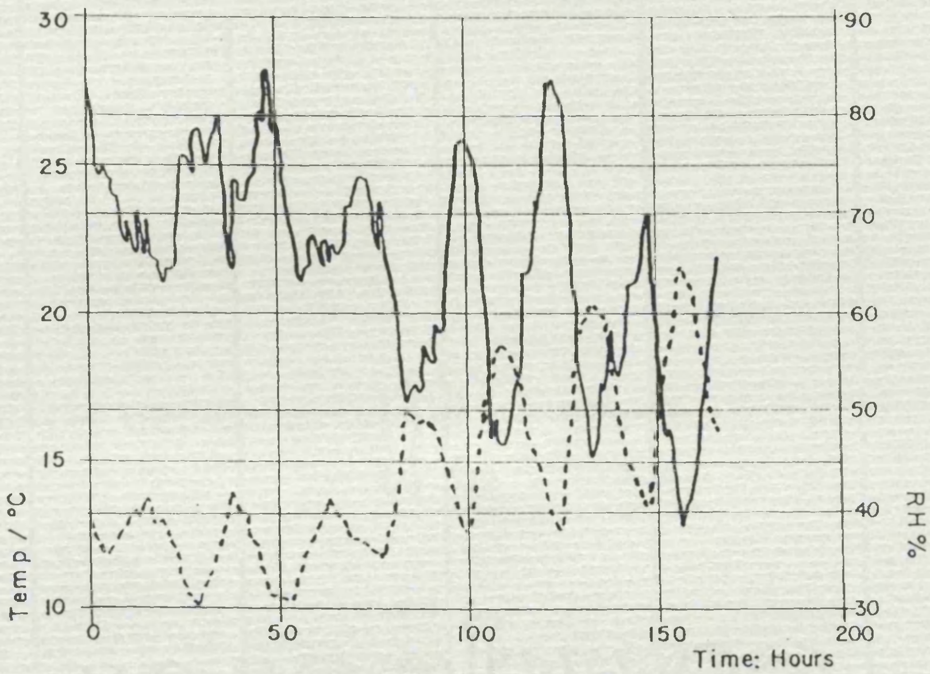


Fig. 6: Courtauld Institute Gallery 5

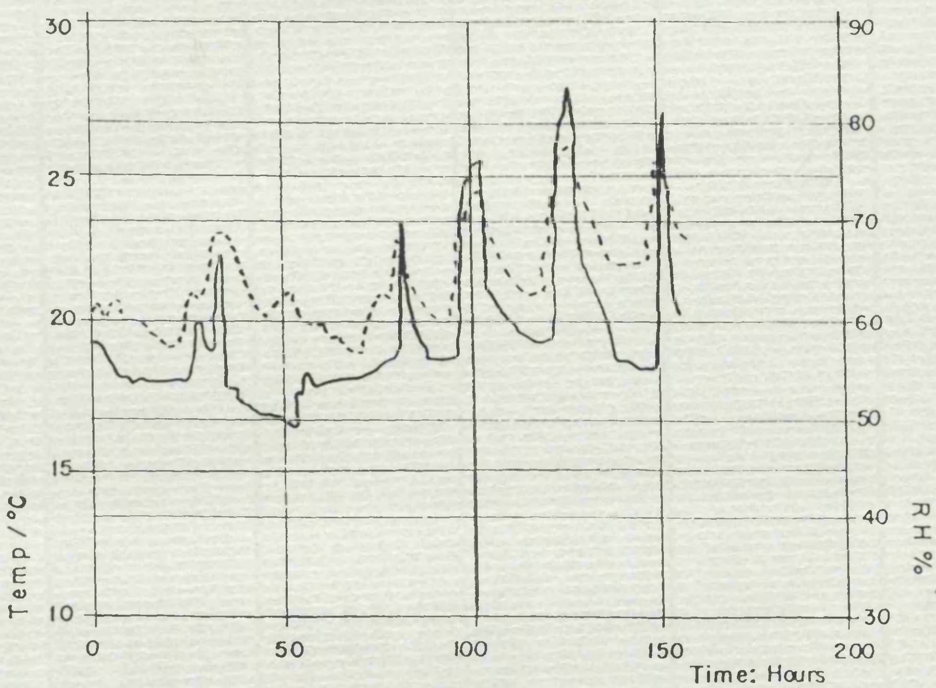
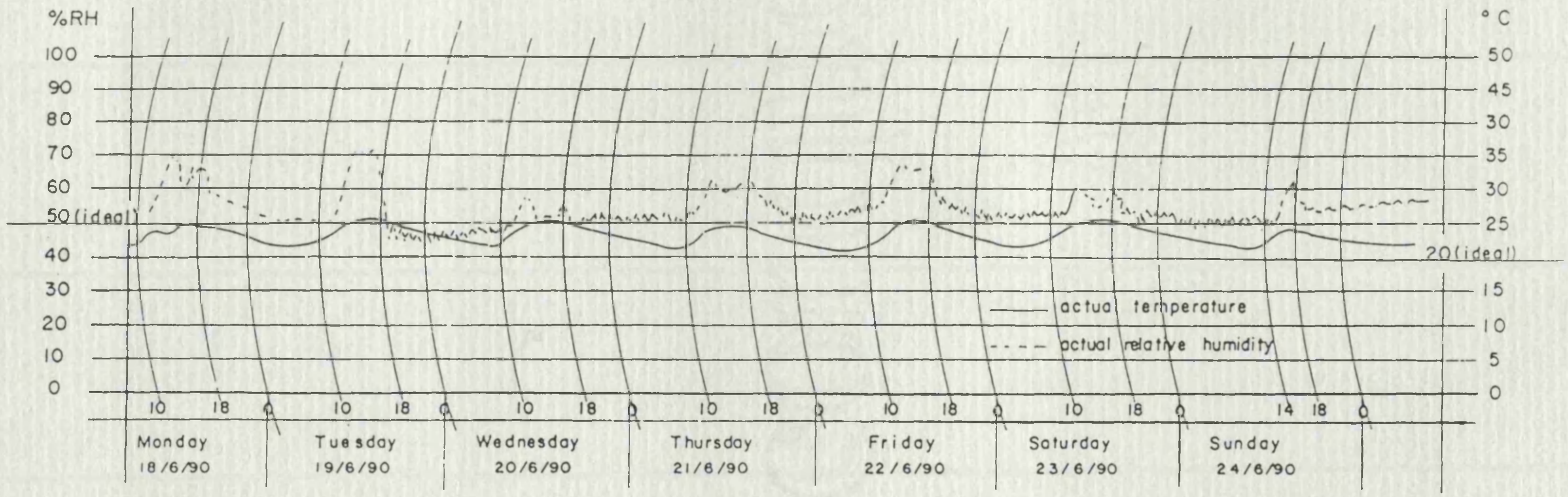


Fig. 7: Thermohygrograph chart showing the effect of visitors on the sealed environment of Gallery 5 (Opening hours: 10 till 18 hours, except Sunday: 14 till 18 hours)



Water vapour produced by the human body inside a space increases the moisture content of the air and creates a vapour pressure difference between the interior and exterior of the room. However, vapour pressure tries to equalise between indoors and outdoors. In the case of the Courtauld Institute Galleries, because of the large number of visitors, the internal vapour pressure soon becames positive with respect to outside (**Figures 8 and 9**).

Furthermore, visitors and staff complained that the environment was 'stuffy' and odorous in the weeks following the opening of the Galleries. The Chartered Institution of Building Services Engineers (CIBSE) bases its recommendations on minimum ventilation rates on the need to limit carbon dioxide (CO_2) concentrations. The maximum allowed concentration of CO_2 to which adults may be exposed for an 8-hour period is 0.5% by volume (ie, 5000 parts per million(ppm)). Many countries have either adopted or are moving to adopt 1000ppm of CO_2 as an upper limit for acceptable indoor air quality because CO_2 is seen as an indicator of the presence of other pollutants. In the UK it is considered a safe and healthy practice to design for 1000ppm, that is equivalent to a ventilation rate of approximately 2 air-changes $hour^{-1}$ (ach^{-1}) in the Courtauld Institute Galleries, assuming a maximum number of 500 visitors in the building. Measurements of CO_2 in one room (Gallery 5) at Somerset House during one week in November 1990 peaked at 3000ppm and the ventilation rate, measured using the tracer gas technique varied between 0.22 and 0.39 ach^{-1} while the average number of visitors to the building during that week was 700[10]. It is likely that during the first few weeks levels of over 5000ppm would have been recorded.

Emergency Environmental Improvements

Emergency measures were quickly taken to try to improve conditions. Increasing ventilation by opening doors or reducing the number of visitors are measures that can be taken to help

Fig. 8: Vapour pressure in Gallery 5 and outside starting at 0 hours on 11th June 1990

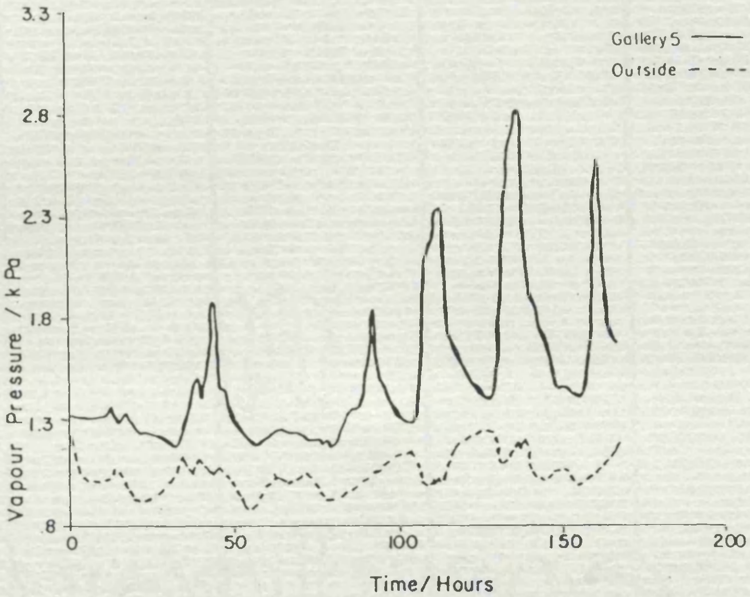
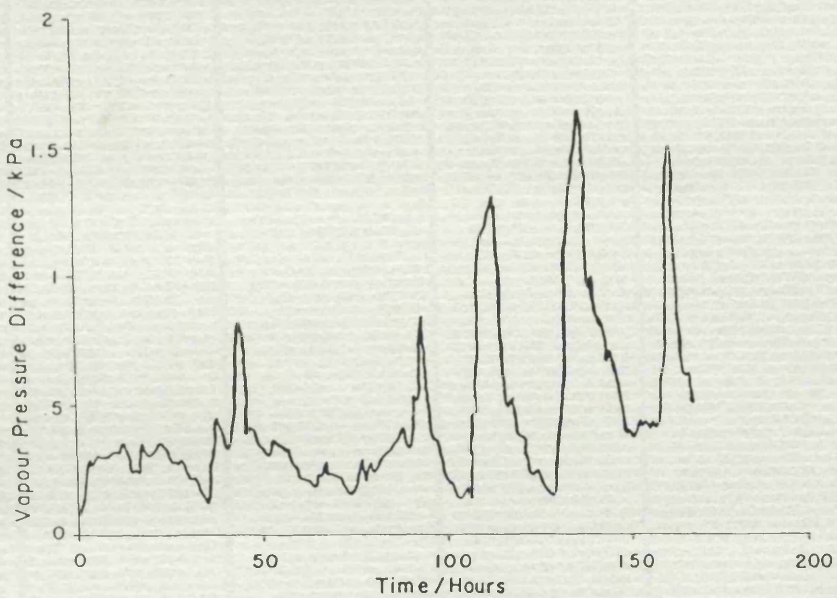


Fig. 9: Vapour pressure difference between Gallery 5 and outside starting at 0 hours on 11th June 1990



lessen discomfort caused by high temperatures and relative humidities and lack of fresh air. However, the north block of Somerset House overlooks the Strand which is usually heavily congested with traffic [**Plate 1**]. Consequently opening windows to relieve internal conditions would enable air laden with dirt and polluted by car exhaust fumes to enter the Galleries and raise the risk of damage to the paintings.

The conditions for staff and visitors deteriorated so that by 1st July, internal doors and later some windows had to be opened to introduce cooler air and to dilute the stale atmosphere. By 12th July the decision was also made to reduce the total number of visitors per day by half from 2000 to 1000 (**Figure 4**). A decline in visitor numbers can be seen on the graph (**Figure 10**).

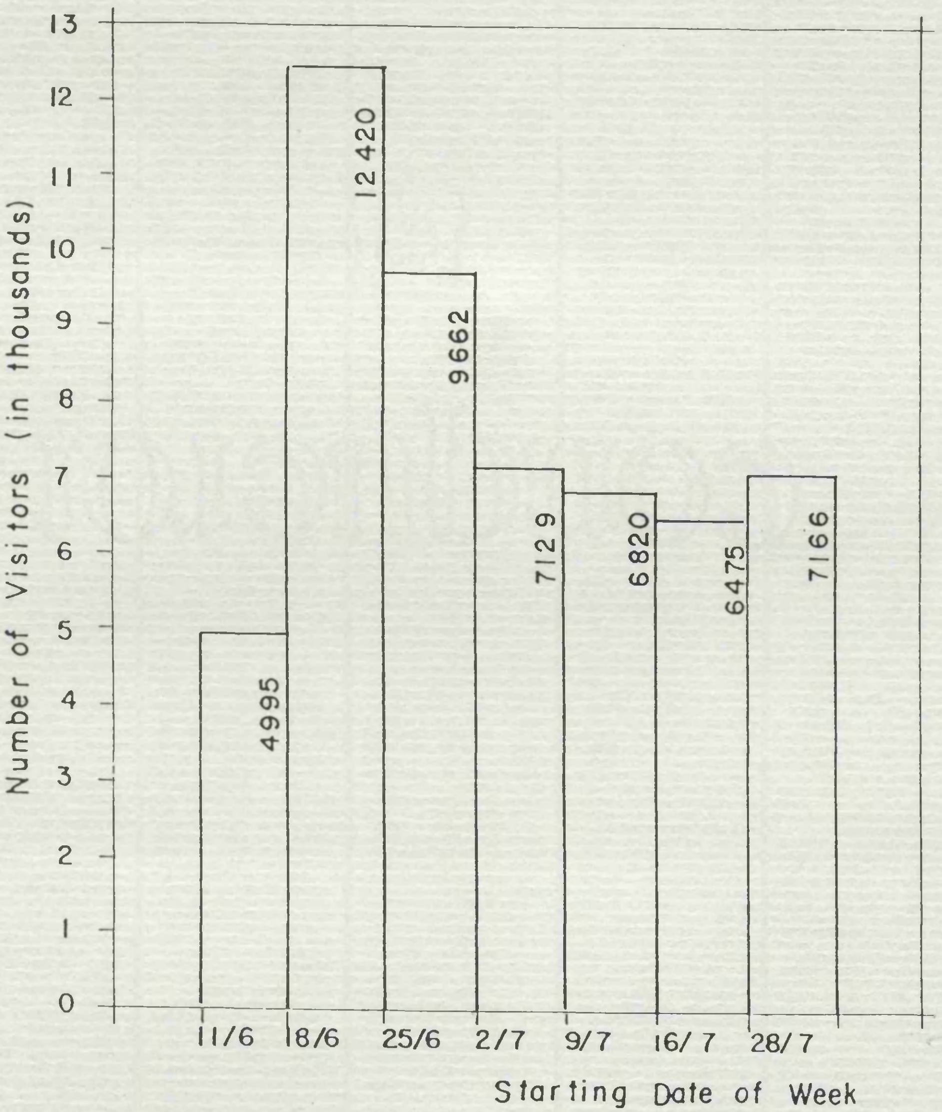
However it is not possible to tell accurately whether the numbers would have declined anyway as the initial excitement over the opening of the Galleries abated.

The effect of increasing the number of air changes by natural ventilation caused wide swings in relative humidity and temperature because of the uncontrolled nature of the ventilation (**Figures 2 and 3**). While this may have helped to relieve the effects of high relative humidity, high temperatures and stale atmosphere for visitors and staff, it did not provide adequate control over the environment for the paintings on display. Fluctuating relative humidity is the single most important cause of long term damage to paintings, especially wood panel paintings. As a consequence of these fluctuations, the room which housed the more vulnerable panel paintings (Gallery 11) was closed to visitors except for 2 hours per day.

Providing a Long-Term Environmental Solution

In the meantime a reassessment of the approach to the control of the environment had begun. It was agreed that short-term measures

Fig. 10: Weekly visitor totals to Courtauld Institute Galleries in June and July 1990



would include comfort cooling for the occupants and ventilation to reduce carbon dioxide levels and dilute odours. However, free cooling through natural ventilation had to be brought under control to reduce fluctuating relative humidity around the collection.

It was decided to install fans installed in the chimney flues and link them by ductwork to the galleries [**Plates 7 to 10**]. They would be activated by carbon dioxide sensors when the level of CO_2 in the Galleries became unacceptable. This meant that maximum use of buffering by the building could be made when there were no visitors present, yet excess moisture and CO_2 could be expelled when the galleries were open to the public. Winter heating for staff and visitors had to be accompanied by some form of humidification for the collection. Humidification and when necessary dehumidification, would continue to be provided by transportable control units. The control of these units would improve if the band-switching humidistats provided with the units were discarded and instead all the units were linked together, as a local area network as part of a Building Management System.

Relative humidity sensors located within the rooms would signal to the controllers to switch the humidifiers or dehumidifiers on or off. These measures would help to provide a level of humidity control for the paintings while human comfort conditions would be improved by controlled ventilation. Whether longer-term improvements are undertaken depends on the success of the short-term measures, the availability of money to the Courtauld Institute to finance further improvements and whether the building and the statutory bodies that control alterations to listed buildings, will allow further changes to be made to the fabric in order to introduce improvements.

CONCLUSION

Good museum design should first ensure that the building is made to last; second, that it provides for the comfort of visitors; and third, that it helps to preserve the collection by providing environmental stability. The Courtauld Institute of Art and the design team had tried throughout the long planning process to satisfy all three requirements but the relationship of all three, especially the interaction of people with their environment was not understood. The measures which were taken to preserve both the building and its contents would have gone some way towards stabilising the internal environment only if the building had not been opened to visitors.

While all three problems had been tackled at different times, they had never all been considered together so that the final scheme which was adopted totally neglected the presence of people. Despite taking the best available advice and conducting small scale experiments, the approach to environmental control on a major refurbishment project had gone badly wrong. It raised fears for the health of the occupants and the safety of the collection, while the effects on the building itself are still largely unknown.

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CHAPTER 6

RECOMMENDATIONS FOR ENVIRONMENTAL CONTROL IN MUSEUMS

The greatest difficulty presented by the conversion of an existing building to museum use is the reconcilation of all aspects that contribute to the success of a museum environment. The requirements of objects, people and the building must be considered throughout the development of a project, but sometimes as the case-study in this report has shown, the contradictions they present may not all be resolved or integrated satisfactorily. The recommendations which follow deal with each of these aspects in turn.

OBJECTS

1. Museums must ensure that objects are kept in appropriate conditions for their preservation. Environmental continuity is more important for the preservation of objects than strict adherence to recommended levels of RH and temperature control. Therefore the starting point of any measures to control the indoor environment must be the conditions in which the objects have reached equilibrium.

2. Before a decision is made on the design parameters for relative humidity and temperature control, architects and consulting engineers should be thoroughly briefed by a museum conservator who has assessed the condition of the collection. Only after such a consultation is carried out, can recommended control levels be designed to suit the needs of the group of objects under discussion.

3. Where possible objects should be grouped according to their environmental requirements and the implications of not doing so for the provision of environmental control should be fully discussed.

4. The band of tolerance within which the climate is allowed to fluctuate and the speed with which changes take place should strike a balance between the conditions objects will stand and what is achievable and affordable by the museum. The relative capital and running costs of different environmental control options must be clearly communicated to the museum client.

5. Environmental conditions around objects, that is relative humidity, temperature and light levels should start to be monitored regularly as soon as the building is handed over. To determine the cause of variations in internal RH, both internal and external vapour pressure should be calculated from measurements of internal and external RH and temperature moisture.

PEOPLE

1. All statutory obligations for the provision of healthy and comfortable conditions for staff and visitors to museums must be met and the legal requirements must be clearly communicated to the museum client. The conflict between statutory temperature control and object-oriented control in occupied spaces must be resolved. Legislation which regulates the minimum and maximum temperature to which public buildings are heated should be more effectively enforced. To ensure adequate ventilation, measures should also be taken to reduce CO_2 levels to below 1000ppm.

2. With the introduction of people into a space, the fabric of a sealed building cannot be relied exclusively upon to buffer internal sensible and latent heat gains and to dilute internally generated pollutants. Mechanical climate control is usually needed.

3. A change in use of a museum building, even in one with

mechanical environmental controls, needs to be planned in advance to ensure that the environment of objects on display or in storage is affected as little as possible. For example, the effect of a rise in the number of visitors as a result of the popularity of an exhibition, or the hire of gallery space for private functions, or opening storage areas to the public should be anticipated, and control systems should be capable of being adjusted to compensate for these changes.

4. On a practical level, the use of warmer clothing by staff should be encouraged and the use of cloakroom facilities by visitors should be obligatory on rainy days. These measures would make control of ambient climate easier and would also reduce the system's energy consumption.

5. Continuous logging of temperature and CO_2 should be carried out as a means of checking the operation of environmental systems and to monitor changes in ambient conditions.

BUILDING

1. Historic, especially listed, buildings can be as demanding in their environmental needs as the objects housed within. Converting a building to museum use normally results in a change in internal environmental conditions. Familiarity is required with the materials and methods of construction of old buildings. The effects that changes in humidity and temperature may have on the building fabric must be assessed. However, a problem common to many old buildings is that the construction is unknown. Furthermore, legislation which controls alterations to listed buildings may also apply if plans include permanent installation of control equipment.

2. An integrated approach to environmental control which considers the interdependence of the building and the

environmental system is required. Total reliance on mechanical systems such as air-conditioning is seldom possible in conversions of old buildings to museum use. On the other hand, total dependence on the buffering capacity of the building fabric will not provide the level of control that may be required.

3. The buffering capacity of a building is affected both by air infiltration as well as its construction. Air infiltration into an unsealed building can cancel the effect that the building fabric may have on buffering external conditions.

4. In most circumstances, museum buildings are required to provide comfort conditions for visitors and a controlled climate for objects. While a naturally ventilated building may mitigate extremes in relative humidity and temperature caused by internal sensible and latent heat gains, it cannot be relied upon in the climate of the UK to provide the tight controls required in a museum. Furthermore, buildings require both heating and humidification in winter, regardless of their capacity to absorb moisture and heat.

5. A building should not be sealed if use by people is envisaged and if mechanical climate control is not planned. However, the fabric of an infrequently visited building, for example a store for museum objects, is capable of delaying and reducing the effect of external conditions if it is sealed. Air infiltration can be reduced by adequate weather stripping, the use of draught lobbies and multiple glazing or the elimination of windows.

6. More flexibility in the application of environmental control in museums housed in old buildings is required. The potential for passive control which an existing building offers should be utilised to reduce reliance on machinery,

to reduce the effective size of equipment and to consume less energy. Environmental zoning should be given serious consideration because not all rooms in a building are affected equally by external conditions. Environmental profiles of individual rooms should be drawn up in order to establish local climatic variations. Cloakroom facilities should be included in every new museum design or conversion.

7. The objective of a partnership between active and passive control is to scale down the mechanical control system to facilitate the transition of an old building to a more technically demanding use and to reduce the impact of unusual loads on a system by applying appropriate technology to achieve environmental control. Since the main purpose of mechanical climate control equipment is to help preserve museum objects, it should be able to operate whenever it is required and not only during the time the museum is open to the public.

8. In the event of a breakdown of control equipment, emergency procedures should be in place to reduce the number of visitors and even to close galleries in order to maintain environmental continuity. Natural ventilation is not a viable option since it can cause environmental instability.

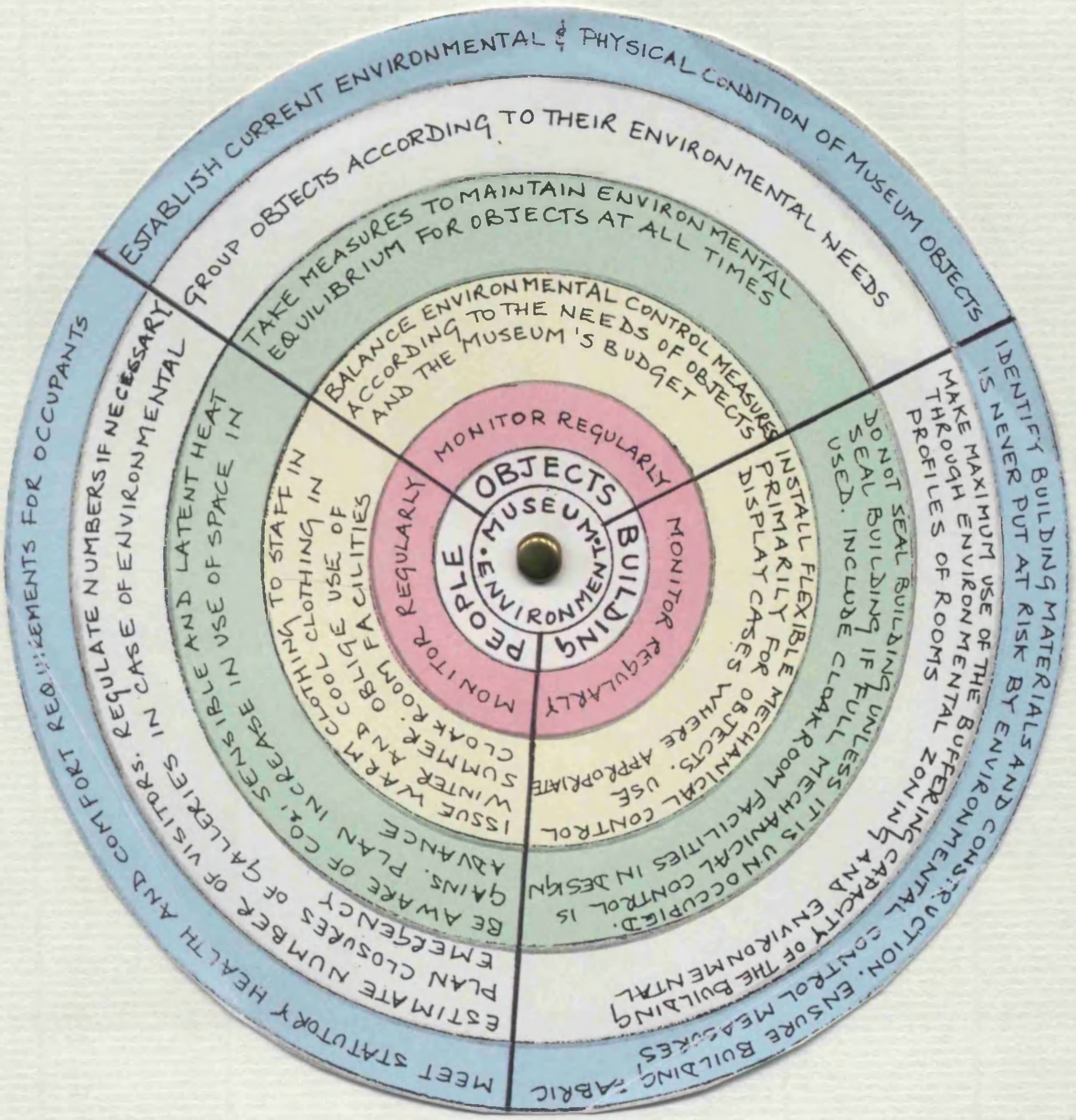
9. Localised protection may be a cost effective form of climate control. Microclimates in display cases segregate objects from people and the building, thereby providing a tight level of control only where it is needed. A well-made display case can stabilise RH changes around objects because display case RH lags behind ambient RH.

10. A change in use of an old building which involves changes in the internal climate may increase the risk of decay of some types of building construction. The condition of the

fabric should be monitored by measuring humidity within the structure.

The problem of balancing the needs of objects, people and buildings does not stop with the commissioning of the building. The three objectives that environmental controls in museums have to meet should be made clear to all who operate the building. A museum environment should control the climate for objects, limit climatic instability caused by people and provide them with thermal comfort conditions while keeping in mind the effect that creating a specialist environment can have on an old building. All three factors, without any one dominating to the exclusion of the others, need to be borne in mind when creating a museum environment. The diagram which concludes this report illustrates the links that should be made between the major factors that make up the museum environment (**Figure 1**).

Fig. 1: The Interdependence of Objects, People and Building in the Museum Environment



Notes:

- Each sector includes the main points that should be considered for objects, people or the building.
- By reading each full circle from the outside inwards, the interdependence of objects, people and building at various stages is highlighted.

PLATES

Plate 1: Store room for Drawing Collection at the Courtauld Institute Galleries in Somerset House

Plate 2: Gallery 2 display case to right of photograph, which was monitored. Note also the humidifier in the centre of the room.

Plate 3: Difficulty of accommodating machinery in a historic building illustrated by the use of the right-hand walk-in cupboard for electrical equipment in Somerset House.

Plate 4: Floor strengthening using iron beams in progress at Somerset House, February 1989.

Plate 5: North elevation of Strand Block of Somerset House. Note the traffic-congested road which the Galleries overlook.

Plate 6: Sealed secondary glazing with integral blind system in windows of Courtauld Institute Galleries.

Plate 7: Uncapping and clearing of chimney flues at Somerset House.

Plate 8: Cleaning the fireplaces at Somerset House in preparation for ductwork.

Plate 9: Ductwork being used to line the chimney flues at Somerset House.

Plate 10: Ductwork emerging into the Galleries via the fireplace.