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Whitby Museum, have been commissioned to illustrate how two museums of different size and scale of operation have succeeded in practice in improving environmental control and energy efficiency. The publication concludes with a list of management priorities for museums wishing to assess their practice in terms of environmental control and energy efficiency.

December 1994

Museum Environments and Energy Efficiency:

Are Our Current Priorities Right?

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Introduction

At a conference at the Victoria & Albert Museum in 1984[1], Gael de Guichen of ICCROM observed – and only slightly tongue-in-cheek – that the best way mankind had yet devised to destroy the objects they valued was to put them in museums. Here they would be bombarded with light, surrounded by unsuitable and often poorly controlled air, subjected to vibration, and put collectively at risk from vandalism, theft, fire, flood, and system failure. Having created such hazards by collecting things and putting them on display, we need to use energy – both our own and from purchased fuels – to reduce the consequent risks. But can we be sure that what we are doing is part of the solution, and not compounding the problem: both locally and globally. How can we help to ensure that things are displayed and looked after more effectively and energy efficiently?

I would like to set the scene for the publication while trying to avoid issues which other papers will cover on the technical side, largely air-conditioning and lighting.

Lighting issues are common in one way or other to all museums and galleries: obtaining the best visibility of the objects in their environment while minimising photo-degradation where this is important. Here the strategy is fundamentally a low-energy one: providing the minimum exposure at the lowest levels at which they can be seen reasonably well, though the ways in which natural and artificial light are actually obtained and controlled are often somewhat roundabout and more energy-intensive than they could be! Annual lux-hour standards (preferably frequency-weighted) are now well understood but less easily applied, particularly where some natural light is required.

On the other hand, only relatively few museums and galleries in the United Kingdom have full air-conditioning: even the National Gallery itself does not have it throughout its premises! Is this appropriate and unremarkable, or a shameful neglect of our national treasures, and should we be using more, not less, energy to preserve them? This paper will therefore concentrate on general principles – for existing buildings and systems as well as new ones – and on temperature and humidity rather than lighting or air quality.

A cautionary tale

Naturally, when designing a new or refurbished museum or gallery, both the client and the design-team wish to do their best. At the early stages, at least, energy-efficiency tends to be fairly low on the priority list, both the client and the design team agreeing that 'no effort must be spared to look after this valuable collection; providing the best and most advanced technology to do it: after all, any extra capital, maintenance and energy costs are trivial in relation to the value of the objects displayed'.

As the project proceeds, life gets more complicated: money runs short and the air-conditioning becomes not quite so full: either in itself or in the coverage of the building. But if the objects then enjoy one non-ideal environment when on display, and another when elsewhere or in storage, have we spent our money on the right things? Is the welter of advanced mechanical technology upon which everything depends an unfortunate necessity or a bad habit?[2]

Once the system is running – and it may take a long time to get it to perform adequately – those trivial costs of energy, maintenance, operation and management often prove surprisingly burdensome and suggestions that a prized object might be sold to pay for them are not well received. Economies are therefore sought, often by pruning bits from the system and maybe even by limiting running hours. Has the best then been the enemy of the good? Would a simpler solution to start with actually have been the more effective in practice?

What sort of buildings are we thinking of?

When discussing museums and galleries, one first tends to think of national institutions such as the National Gallery or the Victoria & Albert Museum. One then remembers smaller municipal facilities, and the constellation of private, public and charitable institutions that have mushroomed over the years. And what about buildings belonging to the National Trust, English Heritage and others? All these fall easily into the Chambers Dictionary definition of a museum as '. . . a repository for the collection, exhibition, and study of objects . . .', and I would like to consider them all here. Most of the underlying environmental requirements are similar, though the solutions differ; some are transferable, others are not.

Is energy efficiency important?

Over the past half-century, there have been a number of pressing reasons why we should use fuel wisely: in the 1940s it was availability, in the 1950s air pollution, in the 1960s we had a holiday, but in the early 1970s came concern about resource depletion followed rapidly by the oil crisis, political problems, and rising costs. In the early 1980s the Iranian crisis gave a second twist to the knife. In the late 1980s we were back on holiday again, with energy-costs in real terms falling back more-or-less to 1960s levels. Then the air-pollution argument came back, but now on a global scale, and many people are now making pious noises but not necessarily doing very much.

Although the prime reasons have gone in and out of fashion, the underlying requirement seems to be here to stay, and it is becoming a professional – and indeed moral – requirement to avoid unnecessary energy-use, certainly where this can be done (as it often can) at little or no additional cost. The architects' and building services engineers' institutions have already nailed their colours to this mast. However, energy efficiency needs to be seen as just one of many performance criteria that need to be met simultaneously: not as an end in itself, more a reward for a good job well-done. It should not be attained by compromising the prime requirements, though those requirements should be questioned if they seem to get in the way of simple, sensible and effective solutions.
To achieve energy efficiency requires:

i. clear intentions.
ii. good design with appropriate technology.
iii. careful execution with attention to detail.
iv. effective operation and management.

To get the best result, all these criteria need to be met simultaneously: quite a tall order – often good ideas get compromised in the follow-through. The requirements also interact: for example, is poor system performance a consequence of inadequate maintenance and management, or was the design too complicated for the management and maintenance skills and budgets realistically likely to have been available? As usual, the answers often lie somewhere in the middle.

I would like to introduce another concept: avoiding energy-dependency. In principle it seems unwise to create situations where maintaining an acceptable environment relies entirely on high-energy flows and the operation of extensive plant in avoidable situations. Energy-dependency tends to bring with it fragility: if something goes wrong, conditions can change dramatically (Fig. 1). It is rare to find organisations whose air-conditioning systems have not let them down in this way. The situation in Figure 1 occurred typically once or twice a year until the controls were altered to shut the system down when such a situation developed, which always seemed to occur at the weekend or over Christmas! However, in principle, it seems to me safer to seek solutions which come to a natural equilibrium and which use low-capacity systems where necessary to fine-tune improvements.

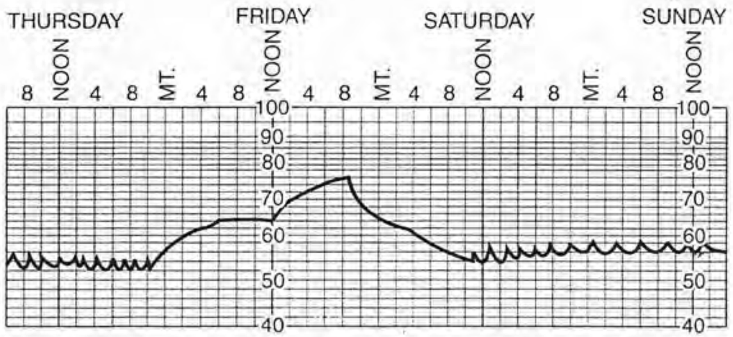

Figure 1 Cyclic fluctuations of 'controlled' relative humidity and consequences of a control failure.

Is it complicated and does it cost a lot?

In the past twenty years, through hard experience and government-sponsored research, demonstration and best practice projects, we have learnt a lot about making buildings more energy efficient. Although few of these projects are directly relevant to museums and galleries – being a relatively small market with very specific individual requirements – the following generalisations seem to be widely applicable:

1. Environmental and performance standards need careful review, but one does not have to lower them, as was assumed in the 'Save It' era. Indeed, they can often be raised.
2. It is not necessary to adopt alternative lifestyles: the best results often come from recognising people's needs, and helping to make the correct behaviour intuitively obvious.
3. Bolt-on technology is seldom the answer. Like many 'go-faster' gadgets, it seldom works as well as intended and tends to fall-off again! The best results come from an integrated approach with the appropriate technology in the right place: often by improving the performance of something you need to have anyway – such as a boiler, a window, controls or a light-fitting, rather than adding extra things that need to be looked after specially.
4. Designers can only do so much. The management and users have a large influence on the final result, generally the more so the larger and more highly serviced the building. However, there are ways of making their lives easier.
5. High-capital investment is not a pre-requisite. On new projects, items which look expensive are often affordable within the overall project budget. For instance, a structure with better thermal performance may cost more but reduce the costs of, and in places perhaps even the need for, air-conditioning plant. In existing buildings, energy-saving measures which would be expensive in their own right can become more cost-effective, if undertaken as part of normal maintenance and refurbishment cycles.

What should the design criteria be?

The thermal environment in museums and galleries has to satisfy three different sets of requirements:

1. *Preservation and display of the contents:* as a general rule, these are not very sensitive to temperature (though low temperatures tend to slow down chemical and biological decay) and much more sensitive to moisture, for which relative humidity is the normal, but not always an entirely appropriate, proxy. Dryness leads to shrinkage and embrittlement; dampness and poor ventilation to corrosion, mould and insect attack; and moisture fluctuations to dimensional changes (which cause surface damage and loosen surface layers) and sometimes even to condensation.
2. *Human comfort:* normally clothed people prefer a higher temperature than most objects require for optimum preservation, but people are not sensitive to relative humidity within quite a broad range.
3. *The well-being of the building:* like the contents, buildings are reasonably tolerant of changes in temperature and are more affected by moisture, and particularly condensation. These arguments are developed further elsewhere.[5]

Somehow all these conflicting requirements have to be balanced, and a suitable compromise reached between comfort, well-being of exhibits, display of exhibits, preservation of the building, and energy and cost-efficient operation. Traditionally the 'best' compromise has been one of high energy, high-capital cost and high fragility: heating or cooling to obtain comfort temperatures for the people (maintained constantly to avoid disturbing the contents), humidity control to recommended levels of RH, and engineering the building so that it can tolerate the consequences.

Commonly, however, the solutions do not hang together, the balance often becomes lopsided, and the collection and/or the building suffers. For example, the *low temperatures* for optimum preservation are not very comfortable and require cooling, dehumidification and fan-energy inputs in summer. In any event, *comfort usually over-rides conservation*, making the building hotter and drier in winter than is good for at least some objects. If winter humidification is provided for the good of the collection, condensation can occur causing the building to deteriorate. *Dual standards* apply, with full environmental control limited to key display areas only, in which individual objects may be for only a small proportion of their lives. For example, in one gallery which I surveyed, great attempts had been made to protect the display galleries from the hostile external environment by surrounding them with ancillary areas such as – you've guessed it – the storerooms! *Energy-saving overrides conservation*, most commonly when:

i. the hours of plant operation are restricted to hours of occupancy and the collection has to fend for itself at other times.
ii. the start of the heating season is delayed to the last possible moment, allowing the building to become relatively cold and damp. When the heating at last comes on, temperature and humidity conditions fluctuate rapidly, causing stress to the objects. A similar situation may apply if cooling is available but its use is delayed.
iii. Sometimes *silly things* happen too, for instance in one museum the extract air from all three air-handling plants went into a common exhaust plenum from which part was recirculated back into the museum. Unfortunately, one of the air handlers served the restaurant!

The role of recommended standards

So what is the job and how does it vary? Are the solutions appropriate for the whole range of institutions, from a national museum to a local museum or a stately home? Of course not. But too often people jump to the numbers in the standards book without thinking through the real requirements, and then either follow them slavishly or reject them totally if they seem to be unrealistic.

I would like to see standards as a starting point and not the Holy Grail. For example, take BS 5454: Recommendations for Storage and Exhibition of Archival Documents.[3] It points out correctly that unsuitable environments have caused more damage to valuable objects than any other single

factor. In the Foreword, it therefore says it aims 'for the highest standards that limiting factors allow'. But are the highest standards always the appropriate standards? Or is this yet another instance of 'the best is the enemy of the good' syndrome, discussed by Ivan Illich[4] many years ago? We might all aspire to owning a Rolls-Royce, get on perfectly well in a Mini (at lower cost and with less environmental impact) and find that a bicycle offers the best compromise between convenience, economy, energy efficiency and environmental impact, particularly if a Ford or a train is also available for the more arduous trips! To be fair, the Foreword to this British Standard goes on to say that it gives recommendations only, and that many questions can be answered only in the context of local conditions. However, standards seldom seem to be applied in this way: like it or not, the suggestion becomes the norm.

The Standard then goes on to recommend accurate and constant control of the internal environment's temperature and relative humidity, appearing to place no particular weight on either although, as we have seen, stable humidities are usually the more important. It says that its objectives may be achieved either by air-conditioning or by a building or compartment with high thermal inertia.

But here there is a logical inconsistency: as alternatives the two approaches are philosophically different (although they can be used effectively in combination):

i. Air-conditioning can, in principle, be set up to provide nominally accurate and constant control (though as we all know achieving this in practice is not quite so easy, and that temperature is more easily controlled than RH, which tends to fluctuate to a greater or lesser degree, as in Figure 1 before and after the runaway).
ii. The high thermal inertia (and, where possible, moisture-sponge) approach essentially rates stability and robustness over constancy and fragility; the environment finds its own level (albeit often with some mechanical assistance) and then flywheels through the seasons with stable but slowly drifting temperature and RH.

To insist on engineering precision with a flywheel-and-sponge approach is, to my mind, missing the point. But, as Michael Young says(2:p.222), in our technocratic society 'evening out natural fluctuations has become an egalitarian enterprise which it is heresy to question'. But this is essentially a modern obsession, and one has to consider how so many historic objects ever survived into the 20th century without the benefit of modern technology. However, where we must have constant conditions, the flywheel and sponge can often make the engineering systems less costly and energy-consuming, and the resulting environment less energy-dependent.

Low-energy approaches to control of the internal environment

In display areas of national institutions there may be no alternative to full air-conditioning: the crowds of people impose wildly fluctuating heat and moisture loads, and conditions may have to be held at some sort of international standard so that objects can be transferred from museum to museum and country to country without major environmental shock. Even here, to improve energy efficiency, conditions are now beginning to be allowed to drift: a practice which originated, I think, in Canada.

Perhaps we can learn some lessons from what happens to sensitive museum objects in transit. Nobody quite trusts air-conditioned lorries and aeroplane holds, 'buffered' cases and containers are often used, well-insulated and sealed, with hygroscopic equilibrium established between the object and its immediate environment. The same principle is used in buffered display cases which are sometimes used to protect valuable items where there is no air-conditioning or where the prevailing conditions are unsuitable for the object concerned.

A low-energy approach starts with the needs of the collection and an understanding of the climate. Some items need practically no environmental control; most need some stability of moisture content (however they often tolerate slow drifts as the weather changes) but are fairly indifferent to temperature; others require tighter control. Gary Thomson[10] suggested two grades of control: Class I (fine – though not in fact very fine, allowing ±5% RH and summertime temperatures up to 24°C) and Class II (coarse), to which one could add a lower RH for metals, and – as advocated by the Museums & Galleries Commission – tagging and special treatment of objects with individual needs, for instance those which have been waterlogged and prefer a very humid environment. And remember that, where the conditions are not too bad, things may be happier to stay in equilibrium with the environment they have got used to, rather than being transplanted into the 'best' environment for a typical object of their kind.

Following these lines, it may be helpful to consider not what are the ideal conditions for an object, but to think more in terms of the amount of environmental instability objects can reasonably endure. If such a risk-management approach seems rather cavalier, remember that the lux-hour approach to conservation lighting already follows similar lines: there is little point in preserving an important object if nobody can see it, but one can limit its deterioration to an acceptably low level!

The relative humidity of the outside air in the UK tends to average around 80% in winter and 70% in summer. Owing to the psychrometrics

only the summer air is damp inside a heated building; in winter the air is usually too dry, as Figure 2 shows. Compare this with Figure 3, which indicates the temperature to which a room would have to be heated for the outside air to give an average 50% RH (both examples excluding internal moisture gains, which might add 5% or so). While the example in Figure 2 would require not only powerful wintertime heating but also humidification, Figure 1 requires less heat and no humidification: a much lower-energy strategy. Now maybe people would object to wandering round cold museums, and the attendants in particular to sitting in them (though local heating could be provided), such a free-running approach may well be beneficial in seasonally used facilities and in storage areas. Now this is not heresy: museums are already doing or advocating it, for example, The National Trust with their 'conservation heating' of buildings which are shut in winter.[6,7] Up to a point, this control of heating for constant RH – rather than constant air temperature – may well reproduce what happened in the past, where buildings with coal and wood fires had high ventilation rates, fairly poorly controlled but relatively low-powered heating, and relatively low-air temperatures generally!

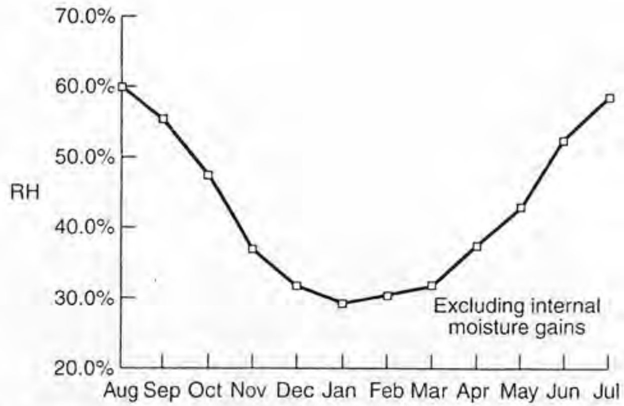

Figure 2 Average monthly internal relative humidity in space maintained at 20°C in London.

Researchers at the National Museum of Denmark (8) have advocated a rather similar approach for museum and archive stores, and indeed some poorly heated stores may sometimes achieve good conditions by default. However, by computer modelling they suggest that where a room contains a large area of hygroscopic material, attempts to lower RH by increasing temperature can cause instability: conditions can be created in which warming up the contents drives off moisture and humidifies the air! Instead, they advocate very low-powered fresh-air ventilation systems with dehumidification where necessary. They consider 'the quick, nervous reaction of orthodox air-conditioning is unnecessary and wasteful when used to control the sluggishly reacting mass of objects in a well-insulated store: a gentle push towards the right moisture content is all that is needed'.

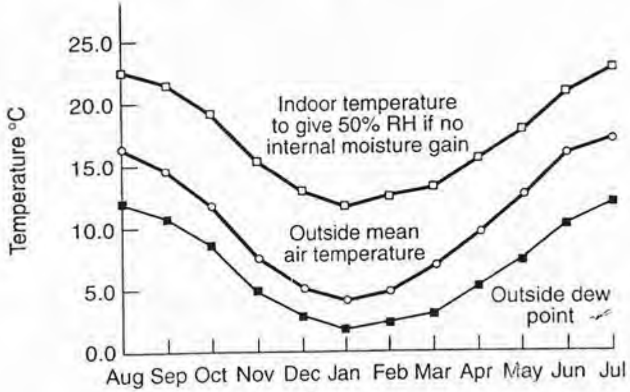

Figure 3 London monthly average outside conditions and required internal air temperature to bring this air to 50% RH.

Determining the priorities

I have talked perhaps too much about standards and about unusual low-energy approaches. But in most buildings – both existing and proposed – work sponsored by the Energy Efficiency Office and others has shown that major economies are usually possible without changing the rules – just by doing the simple things well.

The Building Research Energy Conservation Support Unit (BRECSU) has recently coined a term for it – minimising avoidable waste. And there is a lot of avoidable waste around. For new buildings effective design and planning can be used to reduce the energy requirements and energy-dependency of the building and the loads falling on the building services. The services themselves can be better designed using a number of straightforward rules:

i. Select efficient equipment. This can be particularly rewarding for those objects in museums and galleries which run for twenty-four hours per day. Make sure, too, that these systems are restricted to the areas which really need them!
ii. Consider part-load operation. Often systems are designed to meet the worst case and run uneconomically at other times. For example, heating plant sized to meet peak wintertime loads may operate uneconomically for most of the year, particularly if it stays on in summer for border-line duties. Fortunately well-controlled modern condensing gas boilers can solve a lot of these problems, but to date very few people have been specifying them.
iii. Avoid the 'tail wags the dog effect' where large systems have to remain on to service very localised needs in space or time. Try to provide for these individually.
iv. Understand where the energy is going. The instant reaction is that energy efficiency is predominantly about heating and insulation, but electricity tends to cost four or five times as much per delivered unit and generates 2.5 to 3.4 times as much carbon dioxide as oil or gas respectively. In air-conditioning systems, fans and humidity control systems tend to be the hidden energy-wasters. Consider their design and operation carefully: is heat fighting cool for humidity control and should the fans really have to run flat out all night?
v. Avoid unnecessary technology. It is usually best to do what you have to as well as possible before starting to superimpose systems to try and do it better.
vi. Provide effective and user-friendly control and monitoring systems with suitable reporting and alarm facilities. And try to make sure that it switches plant right off when it is not needed: all too often things stay on unnecessarily 'just in case', for situations which it should be possible to anticipate.
vii. Consider the ordinary systems too: domestic hot water, the offices, the restaurant, lighting and ventilation in the corridors and toilets – often they give rich pickings.
viii. Make sure that the appropriate person or persons 'owns' the task of running the building both well and energy-efficiently.

Conclusion

I can do no better than to quote Gary Thomson[9] who used to be Scientific Adviser at the National Gallery: 'There is something inelegant in the mass of energy-consuming machinery needed at present to maintain constant RH and illuminance, something inappropriate in an expense which is beyond most of the world's museums. Thus the trend must be towards simplicity, reliability and cheapness. We cannot, of course, prophesy what will be developed, but I should guess that it will include means for stabilising the RH in showcases without machinery, use of solar energy for RH control in the tropics, improved building construction to reduce energy losses, and extensive electronic monitoring'. Fifteen years later the prospects sound rather similar, but we now have more of the tools and more of the reasons to use them. Let's get on with it!

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Biography

William Bordass is a scientist who has had a long practical interest in the design and performance of buildings. Following research in physical chemistry at Cambridge, he held many responsibilities within the architectural and engineering practice of Robert Matthew, Johnson-Marshall & Partners (now RMJM Ltd), where in 1975 he was made Associate responsible for developing the building services engineering group and later a specialist team which concentrated on investigations of environmental and energy performance. In 1983 he set up William Bordass Associates which works largely on design briefs, on field and desk studies of building performance and building research management, with particular reference to environmental control, energy efficiency, new technology and physical and chemical deterioration in existing, proposed and historic buildings. He has carried out a number of energy and environmental surveys on museums and historic buildings.

He was founder chairman of the multiprofessional London Energy Group and has worked on a range of projects for the Department of Energy and the Building Research Establishment.