GENERAL INFORMATION REPORT 56

Mixed-mode buildings and systems
– an overview

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BEST PRACTICE PROGRAMME
ENERGY EFFICIENCY
BEST PRACTICE
PROGRAMME

This document arises from a scoping study carried out for BRE by William Bordass Associates as part of the DETR's EnREI programme. The work was done in close liaison with CIBSE.

CONTENTS

1 INTRODUCTION

PURPOSE OF THIS REPORT

This Report outlines the features, strengths and weaknesses of mixed-mode (MM) buildings and the associated engineering systems, which aim to combine the benefits of windows that open with mechanical ventilation (MV) and cooling. It draws upon a scoping study carried out for BRE and CIBSE in 1996, and an earlier study[1] under the EnREI programme. The Report is aimed at a wide audience including architects, surveyors, engineers, letting agents, commissioning clients, user clients and property investors.

MIXED-MODE DESIGN

The commercial property market tends to see buildings as either naturally ventilated (NV) or sealed and air-conditioned (AC). However, many buildings use combinations of natural and mechanical systems. Few AC buildings have air-conditioning throughout; and NV buildings often have some MV (if only local extraction) and sometimes local AC or comfort cooling.

Mixed-mode buildings and systems deliberately combine natural and mechanical systems for ventilation and cooling. While often regarded as a strange thing to do, it can sometimes offer the best of both worlds. It illustrates an environmentally sensitive, integrated approach, using the building fabric to do as much as possible to create a good internal environment, and adding mechanical and electrical systems to do the rest – as with natural and artificial lighting.

THE ADVANTAGES OF MIXED-MODE

There are many reasons for mixing natural ventilation with MV and cooling systems:

- ‘future-proofing’ – a building that can adapt to a wide range of requirements is more likely to provide enduring value to its owners and occupiers and avoid premature obsolescence
- to satisfy occupants – while people appreciate internal environmental quality, surveys show that they also like to be able to open a window
- to save energy, refrigerants, and the associated greenhouse gas and pollutant emissions by avoiding having and running systems which are not necessary
- to reduce the impact on the environment by having longer-life buildings which consume less energy
- to save money – why pay to install mechanical systems you don’t really need, or to run them when you don’t need to?

APPROACHES TO MIXED-MODE DESIGN

Mixed-mode designs have natural and mechanical systems present together. This may seem like belt-and-braces – and sometimes it is – but appropriate combinations can achieve effective results often at lower cost than full air-conditioning. In terms of comfort, they usually perform well; and energy consumption and the related carbon dioxide (CO_2) emissions tend to be significantly lower than in comparable AC buildings (for example, see references [2] and [3]). However – and as also happens in most AC buildings – energy use can easily be higher than predicted, usually because the mechanical systems run more liberally than the designers estimated.

You do not necessarily have to install both systems initially. A ‘contingency’ approach to mixed-mode makes provision for future addition or removal of mechanical systems. For example, a NV building may be planned to allow MV and/or AC to be added easily – locally or generally – if it is ever required. At the other end of the scale, an AC building may be planned so that natural ventilation, or a combination of natural and mechanical systems, could easily be used if the AC was no longer needed.

Contingency designs are rare, though of course many NV buildings have nevertheless become MM of sorts through the ad hoc addition of mechanical systems. Some NV contingency designs have performed well, requiring few, if any, additional services, and vindicating the approach. For example, The Body Shop’s headquarters in Littlehampton required additional cooling in the ground floor laboratories only.

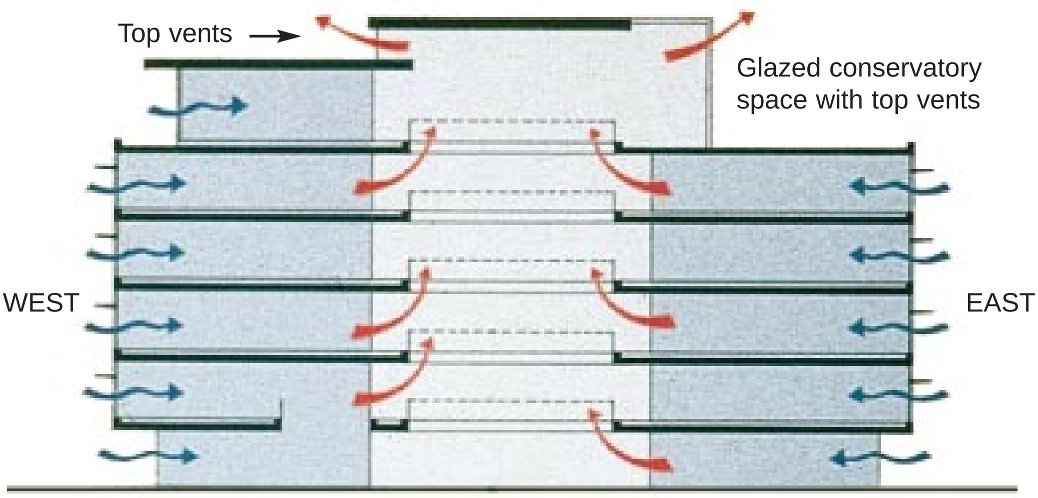
At the time of the 1970’s energy crisis, a few AC offices were designed with the contingency to become NV when the AC needed replacing.

Others, although not explicitly designed for conversion, were planned in such a way that AC was not essential. Some occupiers, particularly local authorities, have already exercised the option to convert from AC, and have improved occupant satisfaction while also reducing energy, maintenance and management costs.

Example of a recent mixed-mode office building. This building for the publishers Addison Wesley Longman at Edinburgh Gate, Harlow, is subdivisible for letting.

Many NV buildings are in fact mixed-mode because they usually have some mechanical ventilation systems in some parts of the building. In this sense mixed-mode has been around for a long time.

To meet property market requirements, this office, pre-let to The Body Shop, had to be capable of being AC. Its contingency design has plant, riser and ceiling void space for a variable air volume (VAV) system. However, with overhangs to shade the summer sun, careful window design, and energy-efficient lighting, its offices work well with natural ventilation alone.



The Addison Wesley Longman building is largely naturally ventilated from perimeter to atrium. Windows at the top of the atrium are automatically controlled in relation to temperature and wind direction. Office windows are under user control and fanlights may be left open overnight. MV through the floor is currently operated in winter only, to provide controlled, draught-free background ventilation. Drawing supplied by CD Partnership (architects).

2 FACTORS TO CONSIDER

REVIEWING THE TRACK RECORD

The BRE study[1] identified 60 substantial MM buildings completed in the UK over the past 15 years, many of these in the early 1990s. Yet more are being designed and constructed, as can be seen from reviews of new designs and reports on recently completed buildings. While most are offices, MM principles can be applied to nearly all types of building, for example, in laboratories and factories, where people now undertake a wide range of activities in office-like environments.

MM buildings have a wide range of occupiers including central and local government, government agencies, defence and police, insurance companies, publishers, IT companies, utilities, universities, manufacturing industries and charities. Early examples were mostly for owner-occupiers, (particularly financial services companies) and the public sector. However, in today's rapidly changing world, former owner-occupiers are now more likely to rent, or to procure their own buildings in joint ventures with developers, and to sell them back to institutional investors. Potentially, the adaptability of MM can be a strong selling point for occupier and investor alike. However, the MM design approach has been slow to catch on in the speculative market, though examples are at last emerging, as shown in this Report.

LOWERING THE RISK

MM concepts can help to create looser-fit, more generic, less specialised buildings which should be more future-proof because they can be readily adapted to the needs of different occupiers, activities, and sometimes even sectors. They can also be more comfortable, cost-effective, and energy efficient.

However, as the concept is relatively new, there are still some areas of uncertainty, particularly:

- lack of market understanding, which increases the commercial risk and makes MM buildings more difficult to value
- suitability and performance of systems
- costs and benefits
- occupant satisfaction
- energy efficiency
- flexibility to meet the changing needs of occupiers
- ease of management – while conventional buildings are not immune from many of these uncertainties, people feel that they are more of a known quantity.

HOW MIXED-MODE COULD HELP YOU

- If you are considering an NV building, is there any reason why it might need any MV or cooling in the future?
  If so, then it may be worth making some contingency provision, not necessarily for a unique solution, but for ways in which systems might be incorporated for individual rooms, zones, wings or floors; or for the whole building. The end result might be some designated routes and holes for services and earmarked locations for possible plant, plus a small amount of structural or space provision to allow change to happen more easily.
- If you are attracted to natural ventilation – perhaps through a concern for the environment, or just a desire to open a window – but there are difficulties in using NV alone, MM may allow its performance to be stretched.
- If you cannot afford AC, then MM may provide as good, or better, functionality and adaptability at lower cost.
- If your building must be sealed and mechanically ventilated and cooled, will this be true everywhere, and for ever? Applying MM concepts to at least part of it might equip it better for an uncertain future.

ENVIRONMENTAL IMPACT

The impact of energy-intensive systems on the environment makes serious professional consideration of passive, low-energy solutions essential. For example, the CIBSE Design and Applications Manual on natural ventilation[4], recommends natural ventilation as the default design strategy, followed by MM, with sealed buildings and full air-conditioning as the last resort. The Air Infiltration and Ventilation Centre[5]

FACTORS TO CONSIDER

Alternate

The developer, British Gas Properties, has already built several speculative MM offices. This one is in Leeds. The present occupier is using the building as a 24-hour call centre and so has had to add mechanical cooling. Although, with the exception of the atrium, it now operates much as an AC building, the MM principles adopted in its design have led to a building which has been adapted for the tenant, has better occupant satisfaction and lower energy consumption than most AC equivalents.

states that all buildings likely to need active cooling should adopt MM design guidelines.

BUSINESS OBJECTIVES

Modern business requires premises that provide:

- cost-effective flexibility
- a greater emphasis on user needs and environmental impact
- lower costs while adding value and behaving more responsibly.

For example, the BRE/DEGW study 'New Environments for Working'[6] (NEW) indicates that medium-depth buildings are best suited to many aspects of tomorrow's changing workplace. Spaces some 15 m across (from outside wall to outside wall or atrium) meet a wider range of requirements than either deeper or narrower plans. Fifteen metres is near the upper limit for natural ventilation (particularly if ceiling heights are constrained and cellular offices are required) but fertile territory for MM options. Indeed, in a context of high uncertainty, high variability, and occupant preferences, the NEW study found that MM systems were often the most appropriate in principle, although sometimes in need of further technical innovation.

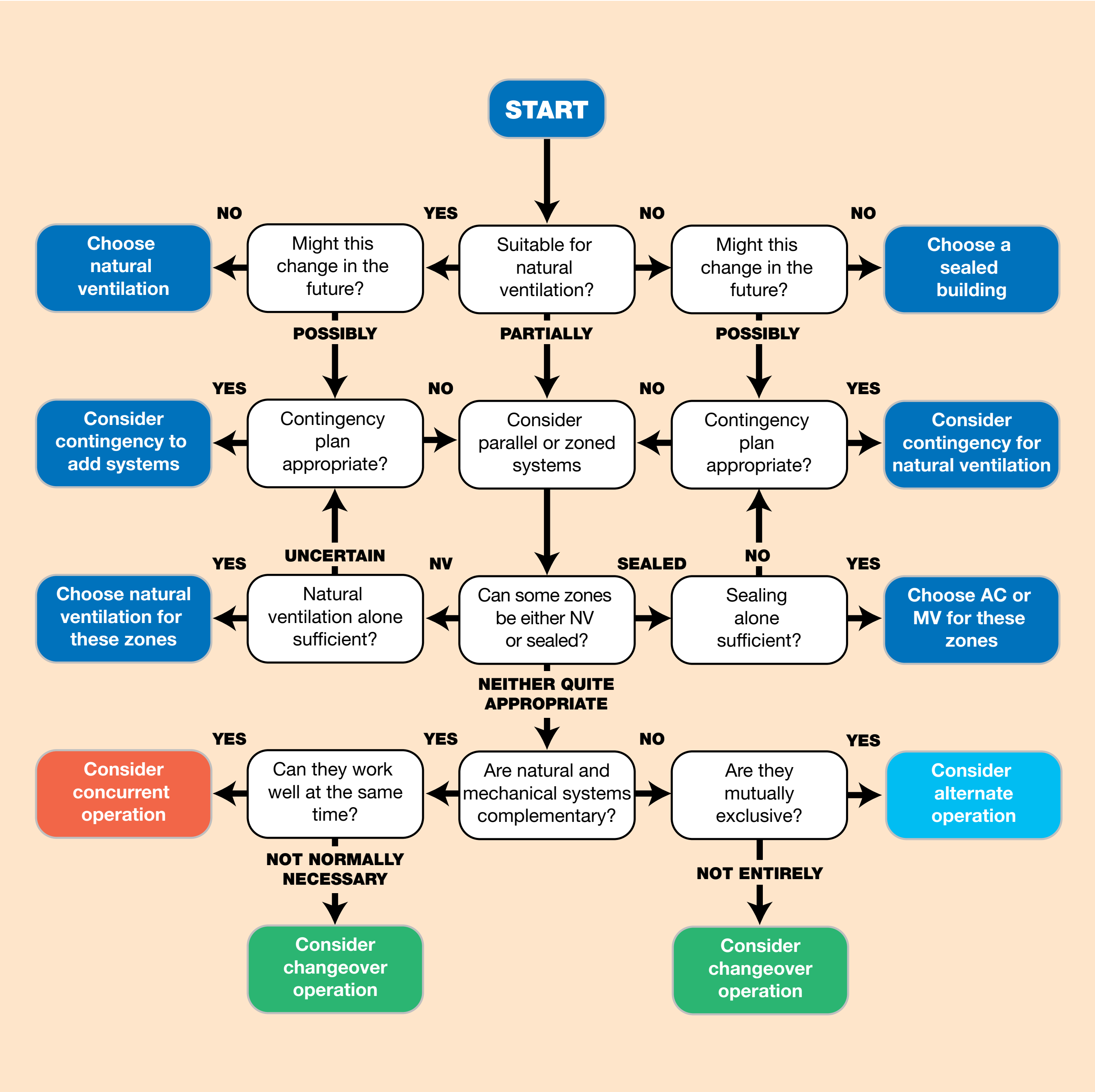
THE RELEVANCE OF MIXED-MODE

No matter how credible MM may appear, it would be foolish to adopt it as part of a building's design unless considered appropriate and necessary to achieve occupant comfort. Some of the key questions for the designer and engineer to answer are shown in the diagram overleaf. This also provides an indication as to which operating strategy to adopt (covered in the next section).

THINGS TO WATCH OUT FOR

Although this Report concentrates on MM design, there are some design issues that MM buildings share in common with other types of building – irrespective of ventilation strategy. The principal actions are highlighted in the checklist on page 9. Each action requires addressing in order to achieve a well-designed, comfortable and properly managed building.

FACTORS TO CONSIDER



This defines three operating strategies for MM systems:

- *CONCURRENT – designed to allow the windows to be opened if required while the mechanical systems are running*
- *CHANGEOVER – designed for either the mechanical or the natural systems to be operating, according to circumstances at the time*
- *ALTERNATE – where a long-term management choice is made to operate the building in one particular mode. For example, at the Leeds office illustrated on page 7 the windows have been locked shut while it is in use as a 24-hour call centre.*

Design checklist

PROVIDE A GOOD DESIGN BRIEF

- Express the design brief clearly in writing. ☐
- Allow the brief to evolve as ideas progress. ☐
- Ensure that final requirements influence the specification. ☐
- Include design objectives in the building contract. ☐
- Use recognised benchmarks (eg reference [7]) in setting performance targets. ☐

REDUCE LOADS

- Minimise loads through attention to building form, orientation and fabric. ☐
- Maximise the use of available daylight. ☐
- Install efficient, well-controlled lighting. ☐

MAXIMISE THE BUILDING'S PASSIVE POTENTIAL

- Avoid unwanted heat gains and losses. ☐
- Ensure appropriate siting and orientation of the building. ☐
- Develop the plan, section, elevation and construction to make good use of natural light, ventilation and solar heat. ☐

CHOOSE APPROPRIATE STANDARDS

- Ensure that standards are realistic. ☐
- Allow standards to develop as part of the design dialogue. ☐
- Make sure standards can be measured. ☐

THE PEOPLE FACTOR

- Choose comfort standards that allow for fine-tuning (people are different). ☐
- Review standards as the project develops. ☐

SYSTEM DESIGN

- Avoid complicated systems. ☐
- Ensure the system operation defaults to OFF. ☐
- Relate comfort standards to context[8]. ☐

COMMISSIONING

- Ensure handover and commissioning procedures are detailed within the contract. ☐
- Allow for fine-tuning. ☐

3 MAIN OPERATING STRATEGIES

It is important that natural and mechanical systems work together and do not clash. In principle, there are three ways of doing this and two of these are illustrated in the case studies opposite.

CONCURRENT OPERATION

The natural and mechanical systems operate together, for example in a building with openable windows and background mechanical ventilation. With some care, this can be an effective and energy-efficient solution. In a building designed for high thermal stability, background ventilation (typically in the range of one to three air changes per hour (ach)) with efficient fans, heat recovery and night cooling may be able to maintain a steady temperature economically; the MV may also be used to extract hot or polluted air at source. Even if the mechanical system seldom makes it necessary to open the windows, the ability to do so increases tolerance and choice for occupants, provides additional ventilation if required, and can permit the mechanical system to be more modestly sized.

CHANGEOVER OPERATION

Here the natural and mechanical systems can operate together in a variety of different ways that may alter with seasons, the weather, occupancy levels, or even the time of day. The intention is to maximise the use of natural ventilation and to bring in the necessary mechanical systems as and when required. A simple example would be a building that is naturally ventilated during the day but, if it becomes too hot by the evening, a mechanical system can pass night air through the building structure to extract heat and precool the structure. Another is where room cooling units, such as fan coils or chilled panels, have interlocks which permit them to operate only when the window is shut.

Changeover applications are often more elaborate than this, with mechanical supply and extract ventilation and/or cooling systems being operated to make up for any shortcomings in natural ventilation performance. Complex strategies in the hands of skilled management can potentially reduce energy consumption. However, for good usability it is important that simple solutions are available that do not ask too much of occupants or management (see section 5).

ALTERNATE OPERATION

Changeover operation can also operate on a much longer timescale. The building, or zone, operates in one mode for a long period – typically years, but certainly for months. This is sometimes known as alternate operation, and an example is illustrated on page 7 (British Gas Properties). For example, part of a building may be AC, with the windows locked shut. However, if the occupancy and use were to be changed, natural ventilation or some hybrid could be used instead. Another example is where a cooling system is activated only in very hot weather, when the occupants would be asked not to open the windows while the cooling system was running.

MAIN OPERATING STRATEGIES

Concurrent

In the Elizabeth Fry Building at the University of East Anglia, air is passed almost continuously through the hollow structural ceiling slabs before ventilating the rooms. This 'trickle charge' arrangement with night cooling and heat recovery keeps the air clean and the fabric at a steady temperature. Windows can be opened if people prefer, but this is primarily for psychological relief. Ventilation rates are boosted for peak occupancies in the lecture theatres.

Changeover

A simple form of changeover operation at the University of York. Laboratories have an exposed, coffered concrete ceiling which helps to stabilise temperatures. When the laboratory is too hot at the end of a summer day, the technician leaves open the louvres in the upper corners of the windows (the openings are designed to be too small for burglars to climb through) and switches on extract fans which draw air in and across the room. Once enough heat has been exhausted (as determined by temperature sensors both in the air and embedded in the concrete ceiling) the University's building energy management system (BEMS) switches off the fans automatically.

Concurrent

The NFU Mutual and Avon Group head office dates from 1983. It has openable windows and an overhead air supply at 2 ach during occupancy. The MV and high ceilings meant that the offices could be relatively deep and the building compactly planned. The designers intended the mechanical system also to be used for night cooling in hot weather, but in fact natural cross-ventilation via high-level windows across the exposed concrete ceiling has sufficed.

Concurrent

Refuge House[3] has windows that open, background MV at 1.2 ach, and heating and cooling using underfloor fan-coil units. The designers intended chilled water to be circulated to the fan-coils only when and where required, but the management finds that the building works more reliably if it is generally available. Energy consumption is still relatively low here because pumping power is modest, the chillers are efficient on part load, and the fan-coils have a wide 'dead' band between heating (which operates below 20°C) and cooling, which comes in at 24°C. Had the windows not been capable of being opened, it is unlikely that this wide dead band would have been acceptable to the occupants.

4 PERFORMANCE OF MIXED-MODE BUILDINGS AND SYSTEMS

ADAPTABILITY

MM systems have inbuilt adaptability, and many original installations have not been changed much (the Leeds building on page 7 is an exception). The variety of operating modes seems to add to their robustness. In addition, occupants tend to complain less about shortfalls in mechanical systems if they are able to open windows when they become uncomfortable.

COST-EFFECTIVENESS

Costs of offices are highly variable, depending on the quality standards adopted. Windows that open do not necessarily entail more expensive façades, because the curtain walling systems used in sealed buildings are often relatively expensive. Overall, MM buildings with extensive MV are reported to cost about 5% to 10% per unit area less than AC alternatives of a similar perceived quality standard. However, those that have almost the equivalent of AC may cost even more than a fully AC building, while contingency designs and those with low-capacity MV or supplementary cooling can be considerably cheaper. Planning may sometimes reduce the usable area that can be fitted on to the site, but usually by less than designing for NV alone. Access to operate windows may also reduce the ratio of usable to net internal area.

MAINTAINABILITY

Maintenance and the fine-tuning required for MM plant tends to be less exacting owing to simpler, lower-capacity systems and wider tolerance margins. However, equipment and controls in some of the more highly serviced examples are not very different from those in an AC building.

OPERABILITY

Many designs are relatively easy to operate. However, difficulties in implementing changeover strategies often seem to be resolved by management running the mechanical systems for longer or more intensively than the designers intended, with consequent energy penalties. The more powerful the systems are, the more wasteful this tends to be. Similar problems occur if intended operating strategies are too complicated and occupiers abandon them. Designers should seek simple, low-energy strategies for use as initial defaults, which can be embellished only if the occupants wish.

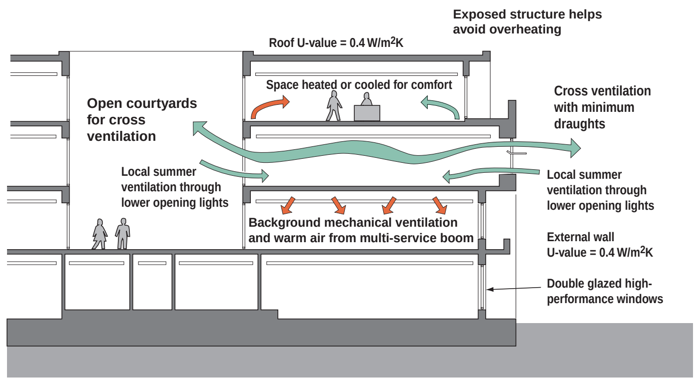
Control and management strategies must suit the management skills available. Unfortunately, management teams that want to be actively involved in tuning systems are rare, so robust simplicity tends to come out best. There also seems to be scope for more demand-activated and interlocked changeover systems, for example by using interval timers and window switches.

Where services are outsourced, there should be suitable contractual arrangements for operating systems effectively, and not just for 'monitoring' them.

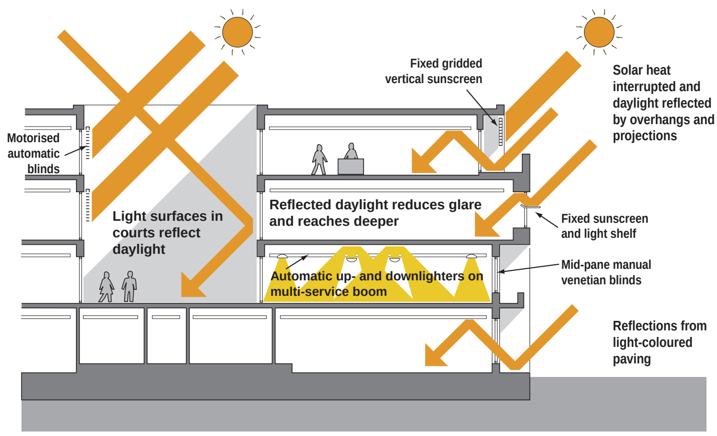
ENERGY EFFICIENCY

In principle, controlled MV with heat recovery promises lower energy costs and lower CO_2 emissions for heating and ventilation than NV alone. However, these have seldom been proven – particularly in the UK fuel economy, where heating is provided by relatively low-cost gas. However, examples such as the Elizabeth Fry Building[9] show what can be done. In relation to air-conditioning, MM buildings should use

The mixed-mode design at the NFU Mutual and Avon Group head office, showing the passive design principles augmented by mechanical ventilation (2 ach).



NFU thermal principles



NFU lighting principles

PERFORMANCE OF MIXED-MODE BUILDINGS AND SYSTEMS

less energy for fans, pumps and cooling. The last two can often be proven; for fans, the picture is less clear. Many recent MM systems have air volumes, specific fan power (SFP) (in watts per litre/sec for both supply and extract systems combined), and hours of operation that are relatively high. This is particularly so where systems designed for occasional use are operated concurrently with the natural systems, and particularly where they are run too much at high speed.

Care is required to ensure that MV systems are designed so that they are both intrinsically low-energy (avoiding unnecessarily high air volumes and SFP) and can be operated to minimise avoidable waste. Attention should be paid to comfort, control and manageability of systems that have a variety of possible operating states; and to minimising the risk of wasteful operation.

Table 1 (on page 14) illustrates some of the energy measures that can be introduced to reduce loads and thus enhance performance. Many of the actions can also be introduced as retrofit measures.

Appropriate, well-designed and well-managed buildings of all kinds can deliver high levels of occupant comfort and satisfaction, and hence productivity. Recent questionnaire surveys indicate that, while one can always find good and bad examples of everything, MM strategies can be particularly successful. Some examples are as follows.

- In the PROBE series of studies in 'Building Services Journal', MM buildings did relatively well. The best building for occupant satisfaction was also MM[9], though this was partly the result of having cellular offices (in which occupants usually report higher comfort levels), and careful attention to detail by the design, building and management teams.
- A recent detailed study by a university[10] looked at occupant satisfaction, comfort and health in seven NV buildings and seven AC buildings. One MM building was added to the dataset for interest, and proved to be the best of the lot.
- A study by Oxford Brookes University[11] found that occupants preferred a refurbished NV office over a comfort-cooled one; but that to have had comfort cooling available in hot weather would have been even better.
- Similar messages are coming from other countries[12], where high scores for both comfort and energy consumption are also being found when control of systems allows occupants to select options, including ventilation through open windows.

Four contributory reasons for this good performance have been identified.

- The designers may have devoted more care to MM than to a more routine solution.
- The same may apply to their client and/or the management of the building.
- The solutions provide some of the advantages of a more natural approach, which people like, but without some of the major disbenefits – for example, summer overheating.
- Occupants value situations, buildings, systems, controls and managements which permit opportunities for simple and rapid adaptation when conditions do not suit them[13]. MM strategies can offer more options for putting things right for both the occupants (with local control) and management (with operational strategies).

MM strategies also have potential pitfalls, which may reduce comfort and satisfaction, unless:

- *strategies are clear, robust and well-integrated* to avoid confusion by management and occupants (who may discern no consistent logic), and clashes between natural and mechanical systems
- *occupants understand how to use in an effective manner the facilities provided* – a vital design task is to make this clear and, as far as possible, intuitively obvious, to occupants; an aim is also to minimise the need for special training of management and operators
- *user interfaces are good* – careful design is essential, with the function clear to the user; conveniently to hand at the point of decision to exercise control; effective in operation; giving good feedback of status; and not permitting permanent lapses into undesired states
- *changeovers do not intrude* – for example, to optimise desired conditions, a ventilation system may automatically spring into life, or switch off. However, occupants sometimes complain about the change itself – perhaps because a draught has suddenly been created or masking noise removed. Such complaints can lead to management operating mechanical systems for longer hours than designers intended, and thus increasing energy use. Changeovers should, therefore, be unobtrusive, and include suitable facilities for user override.

THE FUTURE OF MIXED MODE

MM buildings and systems are becoming increasingly popular and work reasonably well. However, the current emphasis seems to be on the more expensive and highly serviced MM designs. Often, these also have generously sized MV services (sometimes, unfortunately, also cooling); relatively complex operating strategies; and capital costs that approach and occasionally exceed those of sealed, AC buildings. For MM as a whole, it is reassuring to know that people are prepared to invest in this way. However, surveys indicate that, in many cases, simple robust approaches can deliver good levels of comfort while remaining energy efficient and manageable, at a lower cost. As new monitoring results become available, it should be possible to determine which features are most effective.

There appears to be more scope for contingency MM designs. This approach may give comfort to owners, investors and occupiers in having a building in which the services can be upgraded, while avoiding much of the expense and environmental impact of installing and operating these services from day one. Monitoring also indicates that the exercise of devoting sufficient care in briefing, design and management of an NV building which is capable of being upgraded may actually help to avoid the need for such upgrading. It also helps to improve energy efficiency.

PERFORMANCE OF MIXED-MODE BUILDINGS AND SYSTEMS

Item	Actions	Cautions	Comments
Reduce fabric heat losses	Better insulation	Building retains heat gains. Could be problems with winter draughts	More ventilation required for cooling – take care with air distribution
Reduce infiltration heat losses	Better airtightness	Needs careful detailing, site quality and preferably pressure testing	Controlled background ventilation needed to replace some of the lost infiltration
Reduce fabric heat gains	Light-coloured finishes	Preferably not metallic sheen	Ventilated rainscreen cladding over heavy, externally insulated structure?
Introduce time lags to fabric gains	Massive wall construction	Less responsive to heating	Usually worthwhile to avoid summer overheating
Reduce unwanted solar gains	Simplest (and quite common) to use main façade orientation within 30° of N-S	Avoid north side being gloomy	Solar control is easiest towards the south. WSW and W orientations most difficult owing to high gain late in day
Reduce unwanted window gains/glare	Modest window area	Needs careful treatment	Splayed reveals, etc
	Consider internal blinds	Little reduction in heat gains. May obstruct operation if inward-opening windows	Some kind of adjustable blind is usually essential, particularly where there are VDUs. Blinds may block ventilation or rattle
	Consider fins or overhangs	Daylight and view restricted. Fins that become too bright in sunshine may cause VDU glare.	Often needs blinds as well
	Consider mid-plane blinds	Do not suit all window types	Often a practical choice
	Consider external blinds	Expense. Maintenance. Problems in winds and at turbulent corners	Most effective. Auto-control disliked in office areas – provide overrides
	Consider tinted glass (but usually better to use a smaller area of clear glass)	Seldom sufficient to control sun glare No longer 'real' daylight	Supplementary artificial lighting will usually be used. A last resort
Review occupancy gains	Use realistic figures 14 m^2/person common today[14]	There may however be clusters of higher density	Can clusters be dealt with as exceptions, eg by redistributing capacity or using add-on modules?
Reduce heat gains from lighting	Don't over-light: 350 lux on VDU offices Less in circulation areas, etc	Some people may require more – consider adjustable or task lighting	Design for appearance. Not just desktop illuminance
	Choose efficient lamps and luminaires and appropriate circuiting	Lowered efficiency may be necessary for comfortable, decorative effect	Office installed loads should not exceed 15 W/m^2 – preferably 10 W/m^2 [14] or less
	Make good use of daylight, particularly at perimeter and in common and circulation areas	Maximum daylight may be a fragile strategy in workspaces – glare and blinds down	Needs care in window and shading design and control to balance light and glare
	Avoid lighting use when people are out or daylight is sufficient	Maintain pleasant environment for those who remain	Avoid switching on lights unnecessarily Controls should minimise lighting, especially on sunny days
	Provide effective lighting controls	Ensure good manual overrides	See reference [15]
	Exhaust heat from luminaires	May need suspended ceilings, etc	Best to minimise lighting loads
Reduce internal gains from office equipment and other appliances	Select low-energy equipment	Seldom a building design decision	Nevertheless, well worth advocating!
	Avoid equipment being left on unnecessarily. Select auto-slumber equipment if appropriate (but check standby load and switch it completely off where possible)	Seldom a building design decision. Consider dedicated supplies with the rest off overnight	Problematic now more equipment is networked, but nevertheless worth advocating! Note: modern equipment is often left on standby – switch off if possible
	Corral shared equipment into areas with local extract or cooling	If local systems need to run out-of-hours, keep them separate	Good for vending, copiers, shared printers, file servers, communications (eg faxes)
Spread the load over 24 hours	Expose thermal mass of ceilings, etc to reduce temperature swings	Heat needs to be removed overnight. What if extended occupancy?	Can stabilise radiant temperature. Needs natural and/or mechanical night cooling systems
		Winter preheat time and energy consumption may be extended	Usually a minor problem. Possible spur to superinsulated, trickle-charged designs
	Expose thermal mass of floors	Usually need ventilated raised floor	Zonal temperature control of night cooling may be required
Avoid general defaults to ON	Consider presence/absence detection	People may not like it. Presence detection may bring systems on unnecessarily	Allow occupants to make control decisions where possible

Table 1 Reducing the loads

5 INTEGRATING NATURAL AND MECHANICAL SYSTEMS

THINK AHEAD

MM buildings can minimise the need for capital cost and energy use of mechanical cooling by utilising 'natural' or 'passive' means to maintain comfort, with mechanical boosting only to the extent necessary. Cooling needs vary during a building's lifetime – in one building, natural ventilation might meet initial requirements, but subsequent change might create a need for mechanical assistance, at least in some areas. Another building might require mechanical cooling today, but perhaps not tomorrow.

Ideally, when alterations to system capacity are required it should be possible to make changes with minimum disturbance to users, and preferably while the space remains occupied. This requires a clear strategy, service routes with access, space and weight allowance for plant and equipment and (depending on the likelihood and frequency of predicted changes) quick and simple connections for mechanical and electrical services.

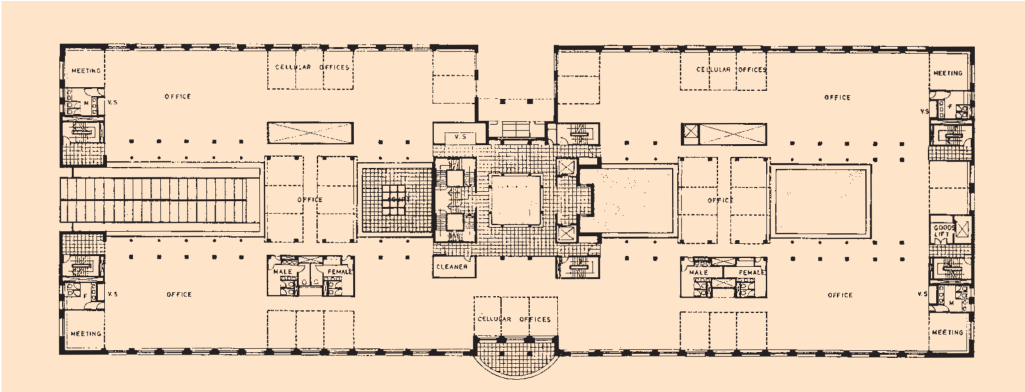
AN INTEGRATED APPROACH

MM buildings require an integrated approach to design and to management, with clear operating regimes to meet changes in use and servicing requirements. The management implications of making alterations to suit the normal range of needs must not be too onerous. In due course, a variety of more standard and well-understood approaches may become available, together with associated products and services. A range of MM solutions is outlined on pages 16 and 17 in order of progressively increasing cooling requirement.

Powergen's head office is designed for changeover operation. It has NV with exhaust via a central atrium gallery, with MV and cooling also available if necessary. During the day, the middle and lower windows can be opened by occupants, and work in conjunction with automatically operated ventilators high in the atrium. At night, the middle and lower windows are shut and the top and atrium windows are used under automatic control as necessary.

Where MV takes care of night cooling in summer, and air quality control throughout the year, the windows can be simpler. In this 'concurrent' system at the University of East Anglia the narrow side lights can be tilted to provide some additional ventilation and psychological relief, or opened inwards for rapid ventilation (and also for ease of cleaning).

INTEGRATING NATURAL AND MECHANICAL SYSTEMS



First floor of NFU Mutual and Avon Group head office. Background MV at an average rate of 2 ach permitted a compact plan form, with typically a 15 m distance between outside and courtyard walls. The MV rate was higher in areas where the geometry did not permit good cross-ventilation, and lower elsewhere. MV could also be used for night cooling, but NV has proved satisfactory and more economical. MV can also be increased to 4 ach in hot weather, but this has not been necessary in practice. However, ducts and plant sizing for 4 ach has had the incidental benefit of making the MV at 2 ach very economical in fan power, at about 0.75 W/l/s.

SOLUTION A
Natural ventilation with background mechanical ventilation during occupancy

A low-capacity MV system (say between 1 ach and 3 ach) can potentially improve air quality in an NV building by providing more uniform controlled ventilation (particularly in winter), plus extraction of unwanted heat and pollutants at source. It also provides some additional air movement in summer. Less reliance upon windows also increases the flexibility of space planning and partitioning.

SOLUTION B
Natural ventilation with extended background mechanical ventilation

One advantage of mechanical ventilation is that the route of the air can be controlled. This has several advantages.

- Where outdoor air quality can be poor, where pollutants and moisture need to be controlled, or where NV is insufficient by itself to meet ventilation and cooling demands, MV can largely maintain the required indoor air quality, while openable windows are retained for occasional use.
- Air intakes can be put in the best positions to take advantage of outdoor air quality and microclimate. For example, air taken in over grass on the north side of a building can be significantly cooler. Take care with solar-exposed and roof-mounted inlets, which can be several degrees warmer. One project surveyed where preheating of up to 8°C was recorded had the air intake at the end of a south-facing valley-gutter in a dark slate roof.
- The air can be passed over or through the structure, which can be precooled or preheated as necessary.
- The air can be supplied from the floor, giving a displacement ventilation effect, although any added natural ventilation will mix with and counteract this.
- Heat can be recovered from the air, or cooling applied.

Background MV at, for example, 2 ach during occupancy and at night can cope with higher heat gains than NV alone. However, long-running ventilation systems must be highly efficient to stop too much electricity being used by the fans.

INTEGRATING NATURAL AND MECHANICAL SYSTEMS

A SFP of not more than 1 W/l/s of air handled is desirable for both supply and extract systems combined. This is an onerous target, but is sometimes achieved as an average with variable multi-speed systems.

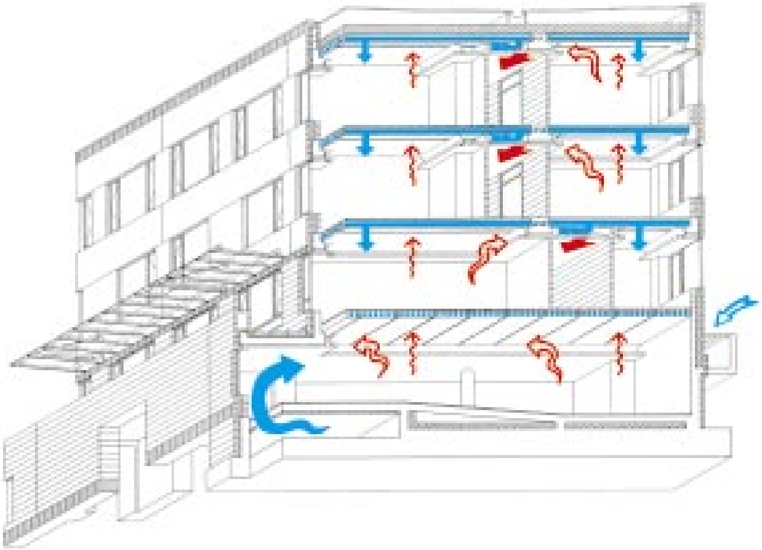
SOLUTION C
Natural ventilation with full-scale mechanical ventilation

This solution combines openable windows with a MV system sized more traditionally, and handling perhaps 6 ach, although low-speed operation and some cooling may also be available. While the market is more familiar with ventilation systems of this sort of capacity in AC buildings, such systems may often be oversized for many MM applications. Fan energy consumption can be high owing to the high air change rate (which usually comes with a higher SFP too) and a tendency for systems to be run for longer hours than the designers anticipated.

SOLUTION D
Natural ventilation or mechanical ventilation with 'top cooling'

Many buildings require cooling for, at most, only a few weeks in the year. There may also be pockets of high heat gain which require more sustained cooling. This can be provided in a number of ways.

- **Via the mechanical ventilation system.** However, there can be control difficulties if different parts of the building need different amounts of cooling.
- **Via local recirculatory fan-coil units**, either direct-expansion, chilled-water or heat pump. These can be free-standing, wall-mounted, ducted, in the ceiling, or under the floor. They are usually either permanently connected and used on demand, or installed locally ad hoc. Another option is an adaptable system having units with quick-release connectors that can be plugged into a 'heat bus', power, controls and condensate drainage as required.
- **Via static cooling units**, such as chilled ceilings and beams, usually piped-up permanently in a building or zone and used on demand. Condensation has occasionally been a problem in hot, humid weather unless tempered and dehumidified MV is used, or the chilled water circulation temperature is not allowed to fall significantly below the dewpoint of the air.



This 'trickle-charged' building at the University of East Anglia passes air through hollow floor slabs. Windows are also openable. If extra cooling is required, outside air is passed through the fabric at night. If extra heat is needed, the building is warmed at night with the system in full recirculation. Fans are three-speed for the offices and seminar rooms and variable speed for the lecture theatres, in which some of the air during occupancy periods bypasses the floor slabs. Monitored annual gas consumption for heating was 33 kWh/m². Annual electricity consumption for fans and pumps (predominantly fans) was 18 kWh/m², and the designers consider that they could probably halve this.

KEY **SUMMER MODE**

- Air cooled by structure
- Return air
- Energy store
- Night-time air intake

6 COMMISSIONING

There is little point in constructing a well-designed MM building unless it is commissioned properly, with the occupants having a good understanding of how the building functions.

HANDOVER

Pressures for handover usually squeeze building services commissioning programmes, so systems and controls may not be checked and tuned as the designers intended. It is also important for MM systems to be robust, adaptable and made as easy as possible to set up, to fine-tune and to alter. The design and operational intentions need to be made clear to management, to individual occupants, to operation and maintenance contractors, and to those who may adapt, equip and alter the building, including space planners and interior designers. It also helps if designers can make clear the requirements that need to be written into outsourcing contracts.

Once the building comes into use, there should also be a contingency fund to undertake ‘sea trials’ in that the designers, managers and contractors can review the building in operation; make any small alterations, particularly to control systems, that may prove to be necessary to improve its functionality; agree and record the most appropriate operating procedures; and to learn from the whole process. This can greatly improve performance, occupant satisfaction and energy efficiency in all buildings, not just those of mixed mode.

INCLUDE APPROPRIATE METERING AND FAULT DETECTION

Management must be able to review performance against its own targets, industry benchmarks and past performance, and be aware if a component or system is not working properly. Sub-meters should be fitted, in particular, to large individual items of plant, to plant and equipment in unusually high (or low) energy areas (for example to computer rooms, restaurants, and large car parks) and to suitable cost centres. Even though today’s BEMSs boast comprehensive fault detection, to date these have seldom included performance monitoring against design and management objectives for the system. For example, for mechanical night cooling it helps to know whether the air is coming in close to outside temperature – in monitored buildings it often did not[1], so faults often remained undetected for long periods.

7 MAINTAINING EQUABLE CONDITIONS

This section concentrates on the factors associated with summertime temperatures, when the successful avoidance or removal of unnecessary heat can be decisive factors in influencing the ventilation strategy.

INTERNAL HEAT GAINS

Experience and computer thermal modelling confirm that acceptable summertime temperatures are often possible without recourse to full air-conditioning, even in offices where everybody has a computer. Thus a good approach is often to design the building as NV, and to consider adding ventilation and cooling services (or potential for services) as necessary, to meet requirements and to provide the required adaptability. Principles of design for NV are outlined in BRE Digest 399[16], with more detail in reference[4].

Internal heat gains (primarily from equipment, lighting and people) are often critical in determining whether NV will work. Table 2 (below) shows the additional measures that typically need to be adopted to find a solution. Beyond these limits, some mechanical ventilation and/or cooling may also be required.

Where usage and heat gains are unpredictable – as increasingly they are in this rapidly changing world – people often become wary about the limits to a NV design. In the 1980s, heat gains – particularly from office equipment – were often overestimated, and led to unnecessary and wastefully oversized AC. Better information is now available[17]. The MM approach can also help to reduce the risk of underestimation (or indeed overestimation) by 'stretching' the performance of NV and allowing progressive increases in the provision and use of mechanical services. Further information on internal gains is given in the box overleaf.

Other sources of unwanted heat gain should also be kept to a minimum, in particular by:

- effective use of thermal capacity in both structure and envelope
- good window design and control, including solar control
- avoiding any unnecessary heat gains through the ventilation plant, for example through excessive fan power, poorly located air intakes, or heat recovery systems that are not properly bypassed in hot weather.

VENTILATION, THERMAL MASS AND WINDOWS

Natural ventilation routes, likely driving forces (stack and wind pressure), resistance and obstructions to flow, and means of control must be considered carefully. Depth of plan, building height, and internal partitions will all affect the likely flows. Internal arrangements, window design and control (including access to controls), security and noise implications will also affect occupant perception of temperatures and ventilation rates. Air movement may be used to lower perceived temperatures, but occupants should be in control of its location and direction, or they may otherwise regard it as a draught.

Table 2 Design parameters for natural ventilation
Internal heat gains and likely suitability for natural ventilation (developed from figure 2 of BRE Digest 399)

Design parameters	Heat gains (including people, lighting, office equipment and solar) W/m² 10	20	30	40
Impact on architectural form and finishes	Little →			Large
Suggested minimum room height (m)	2.5	2.7	2.9	3.1
Easily controllable window opening (down to 10 mm)	✓	✓	✓	✓
Trickle ventilators for winter	✓	✓	✓	✓
Control of indoor air quality (could be manual)	?	?	✓	✓
Design for daylight to reduce heat gains	?	✓	✓	✓
Daylight control of artificial lighting	?	?	✓	✓
100% shading of glass from direct sun	?	✓	✓	✓
Cooling by daytime ventilation only	✓	✓	Difficult	
Cooling by night-time and daytime ventilation	✗	?	✓	✓
Internal exposed thermal mass	✗	✗	✓	✓

✓ Essential ? May not be required ✗ Not necessary

MAINTAINING EQUABLE CONDITIONS

ESTIMATION AND MANAGEMENT OF INTERNAL HEAT GAINS IN OFFICES

Occupancy levels

Frequently office occupancy is estimated at about 10 m^2 of usable area per person, but recent studies have shown that in use they are seldom this densely occupied overall. In its Specification for Urban Offices[14] the British Council for Offices (BCO) now recommends 14 m^2/person. The sensible heat output of a person in an office is typically 100 W[18].

Nevertheless, many offices have pockets of dense occupation. The question is then whether the whole building and its services need to be designed to accommodate this, or whether it can be dealt with as a special case using adaptable MM principles.

Equipment heat gains

Ideally the designer and client should estimate the likely range of equipment gains by careful consideration of current and future requirements, including measurement where necessary. Background information is available in reference [17] and other more detailed sources. Do not rely upon manufacturers' nameplate data, and make appropriate allowances for diversity in use.

In the absence of such information, as a reasonable industry standard for a speculative office, BCO[14] now recommends that one should assume 15 W/m^2, with some pockets of up to 25 W/m^2, anything beyond that being regarded as a special case requiring special servicing.

The recent PROBE studies reported in the CIBSE Journal tend to confirm 15 W/m^2 as a reasonable figure for open-plan areas with typically one computer per desk in offices occupied by financial services companies. Only small areas (for example, customer service centres and computer development offices) used more than this, while several companies used much less. Specialist areas such as dealing rooms can, of course, use much more, but routinely have their own independent or supplementary cooling systems. In other parts of the office, for example management suites, office equipment heat gain densities are usually lower.

Occupiers can reduce equipment heat gains by careful selection and use of equipment. They can also locate some items of hot or polluting equipment in areas in which their heat gain and ventilation requirements can be dealt with locally and have less effect generally. For example, photocopiers, shared printers, file servers and vending machines should ideally be located outside the main office area, say in rooms – or at least under hoods – with extract ventilation, and located near entrance points and other accessible positions. This is often desirable in any event to help improve air quality.

Heat gains from lighting

With a trend to illuminance levels of some 300-400 lux to suit both paper and computer screen use, improvements in lamp and luminaire efficiency, and better control, heat gains from lighting have been falling. One can now light most offices at an installed power density of 10-15 W/m^2 or less. If daylight is used well, with effective glare control which admits sufficient diffuse daylight, much of this can be switched off at times of high solar gain.

MAINTAINING EQUABLE CONDITIONS

THERMAL MASS

Effective use of thermal capacity can allow the effects of heat gains during the occupancy period, together with the cooling effect of outside air and other ambient sources, to be spread over 24 hours. This helps to even out temperatures, lowering the peaks and reducing, and sometimes eliminating, the need for any mechanical cooling. A cooler structure will also improve comfort by lowering the radiant temperature.

Most buildings already contain sufficient thermal mass – particularly in their floorslabs – but it is often isolated from the indoor climate by, for example, suspended ceilings. Thermal inertia can be increased if larger areas of structure are put in contact with the indoor climate, for example by using exposed concrete.

To enhance heat transfer further, fans can increase airflows over the structure, for example in ventilated voids under a raised floor, or through airways in the structure itself (for example by using hollow precast concrete floor slabs). Structures and ceilings may also be water-cooled, perhaps with groundwater via embedded pipes.

Thermal mass in façades and roofs is also desirable. In roofs there are often arguments about this. Lightweight structures tend to be cheaper. However, thermal mass may be essential if the top floor is not to get hotter than those below, otherwise it may need more mechanical services. Thermal mass in façades not only provides added stability, but also delays the entry of any solar heat absorbed by the outside surface. Ventilated layers can also be incorporated.

Any unwanted heat stored in the fabric during the day must be removed at night, usually by ventilation. Natural ventilation at night can be very effective but can compromise security and may need automatic control. Mechanical assistance can be easier but uses more energy and is best combined with fabric thermal storage. Night ventilation can sometimes cool the building too much for early morning occupants, and in some cases it can bring the heating on. Extra care must therefore be taken in developing effective control strategies, and verifying their operation in practice.

Where natural ventilation predominates, windows need to permit a wide range of adjustments. Typically, they will have a large lower element, which provides the view, and that can be opened wide if necessary, plus an upper element that can be used for cross-ventilation and left open for night cooling while remaining secure and weathertight. Increasingly, the upper element is being automated for better control of night cooling. Trickle ventilators may also be required. (See Good Practice Case Study 308 'Naturally comfortable offices – a refurbishment project'[11].)

WINDOW DESIGN

Where natural ventilation is the prime cooling source, sophisticated window design will be necessary – often with a choice of opening element and perhaps some automatic control (with manual override) – and effective control of unwanted solar radiation. In designs with continuous MV, windows can potentially be simpler, depending on the tasks they have to perform. This may reduce overall capital cost but can increase cooling loads and sacrifice some future adaptability. All windows require effective control of sun and sky glare, which – even if automatic – should also be capable of adjustment by individual users. But remember that the use of solar control glass can reduce the amount of daylight and change the quality of both daylight and view dramatically. Use such glazing only as a last resort after employing other measures to control the solar gains.

8 CONCLUSIONS AND POINTS TO WATCH

CONCLUSIONS

Key conclusions are as follows.

- Carefully designed and well-managed MM buildings and systems can combine the best features of natural ventilation and air-conditioning.
- A contingency provision to add cooling may be sensible if a comparison with an AC building is borderline.
- MM buildings can be more sensitive to the requirements of the occupants and organisations, and improve the fit between requirement and provisions, with greater flexibility, less cost and less waste.
- The performance of monitored examples have been good in terms of comfort levels, although sometimes at the expense of energy consumption – which was nevertheless low in comparison to the vast majority of AC buildings.
- There is scope for improvements in control, manageability, adaptability, energy efficiency and cost-effectiveness.
- Air-conditioning may be seen as essential where a site is particularly noisy, polluted or needs to be built to high density on an awkward site. However, MM principles are often applicable to these situations, at least for part of the building.

THEMES

The scoping study revealed the significance of:

- clear strategic approaches
- manageable systems that worked together, did not clash, and were not unnecessarily complicated
- energy-consuming systems that were unnecessarily powerful, inefficient, or turned on unnecessarily; and which did not fight each other
- improving controls – for occupants, for management, and for effective energy-efficient operation
- effective use of the controls present through monitoring and dialogue between the designers and the facilities management team
- developing clearer standards
- illustrating generic exemplars.

The potential was also identified for design approaches that could reduce the amount of plant which was a permanent (or semi-permanent) part of the building. Instead, adaptable systems and modular components could be added when and where necessary and be readily adapted and exchanged.

POINTS TO WATCH

- Natural ventilation must be easily operable, and must not let in rain nor compromise security requirements.
- Take care with MV control. In many buildings studied, MV was used too liberally. Night ventilation was also wasteful, sometimes with recirculation, heat recovery or even heating wrongly brought into operation.
- Make sure that any fans do not waste electricity. At many sites studied, fans used too much power, were on for too long, or at too high a speed.
- Noise, dust or insects through open windows may be a nuisance. Problems can be reduced by careful design. When natural and mechanical systems are operating concurrently, windows will tend to be open much less than with only natural ventilation, but may nevertheless be highly valued by the occupants (improving reported comfort and satisfaction levels).
- Building plan depth or cross-section may restrict planning options. With mechanical boosting, constraints will be less severe than with natural ventilation alone. However, any deep-plan building will tend to have less individual control and outside awareness and hence occupant tolerance.
- Adapting ventilation and cooling systems to changing needs must not put an unreasonable burden on management. Designs with a good range of capabilities and which permit straightforward alterations and upgrades should be favoured.
- Control strategies must be easy to understand by management and occupants. Where possible, occupant adjustments should be intuitively obvious. Where this is not possible, then appropriate interlocks, overrides, feedback devices and clash alarms should be provided.

REFERENCES

[1] **Department of the Environment, Transport and the Regions.** General Information Report 31. 'Avoiding or minimising the use of air-conditioning – A research report from the EnREI programme'. DETR, London, 1995

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[4] **Chartered Institution of Building Services Engineers.** CIBSE Design and Applications Manual. 'Natural Ventilation in Non-domestic Buildings'. CIBSE, London, 1997

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[13] **'Field studies of thermal comfort and adaptation'** (ASHRAE Technical Data Bulletin 14 (1), January 1998) is a compilation of papers on this subject

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[15] **Building Research Establishment Ltd.** A I Slater, W T Bordass and T A Heasman, BRE Information Paper 6/96. 'People and lighting controls'. BRE, Garston, 1996

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[17] **Department of the Environment, Transport and the Regions.** Good Practice Guide 118. 'Managing energy use. Minimising running costs of office equipment and related air conditioning'. DETR, London, 1997

[18] **Chartered Institution of Building Services Engineers.** CIBSE Guide Section A7, 'Internal heat gains'. CIBSE, London, 1986

DETR documents referenced in this Guide have been produced as part of the Energy Efficiency Best Practice programme, the buildings-related aspects of which are managed by BRECSU. Free copies can be obtained from BRECSU (see back cover for details).

FURTHER READING

BRE PUBLICATIONS

BR 345 Environmental design guide for naturally ventilated and daylit offices

NatVent® Guide

Natural ventilation for offices

DETR ENERGY EFFICIENCY BEST PRACTICE PROGRAMME DOCUMENTS

The following Energy Efficiency Best Practice programme publications are available from BRECSU Enquiries Bureau. Contact details are given below.

Good Practice Guide

257 Energy-efficient mechanical ventilation systems
276 Managing for a better environment. Minimising running costs and impact of office equipment

General Information Report

48 Passive refurbishment of the Open University – achieving staff comfort through improved natural ventilation

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