June 1996

FIFTH DRAFT

MIXED MODE VENTILATION AND COOLING SYSTEMS IN BUILDINGS

A scoping study for the Building Research Establishment

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Draft report of a scoping study for BRE by Bill Bordass

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1 SUMMARY AND CONCLUSIONS

1.1 Background

1.1.1 WHAT IS MIXED MODE?

Mixed Mode (MM) is a term for hybrid buildings and systems which combine natural and mechanical ventilation and cooling. Strategically, this can be done in three different ways:

- *Contingency:* with openable windows and planned for easy addition (or removal) of mechanical systems.
- *Zoned:* with different services in different parts of the building.
- *Complementary:* with natural and mechanical systems present together.

1.1.2 WHAT DOES MIXED MODE OFFER?

The study has identified three main groups of objectives:

1 "Tunable" buildings with longer life, greater adaptability of space and services, less waste, lower cost, and fewer burdens for management.
2 Better occupant satisfaction, by combining the perceived advantages of openable windows with mechanical servicing for suitable levels of health, safety and comfort.
3 Reductions in energy use and the associated greenhouse gas and pollutant emissions.

1.1.3 WHERE DOES IT FIT IN?

Until recently, MM was regarded as on the fringe of good practice, a somewhat shaky middle ground between natural ventilation (NV) and full air-conditioning (AC). An alternative opinion is that mixing natural and mechanical systems should be a perfectly normal way of doing things - just as with natural and artificial lighting. While we endorse this opinion in principle (and in appropriate circumstances, MM can be superior to both natural ventilation and air-conditioning) it is also true that some parts of the ground are still shaky.

1.1.4 COMBINING NATURAL AND MECHANICAL SYSTEMS

Where systems are *complementary,* a wide range of combinations and operating modes is possible. The operating strategies - which can change with time - normally fall into one of three main groups:

1 *Concurrent.* Where natural and mechanical systems operate together.
2 *Changeover.* At certain points, the operating mode of the system changes: for example with natural ventilation in the day and mechanical removal of excess heat overnight; or with mechanical systems operating only in cold and hot weather.
3 *Alternate.* Once the choice of natural or mechanical has been made, it stands for typically many years, for example with close-control air-conditioning in a naturally-ventilated shell in which the windows have been locked shut.

1.1.5 SCOPE OF THIS REPORT

This report is of a scoping study carried out in the first half of 1996 to:

- review the state of the art knowledge of MM systems;
- clarify the scope and methodology of any further case study, thermal modelling or market research work required to support the production of a proposed CIBSE Applications Manual;
- as an initial input to raise the profile of MM amongst the architectural and engineering professions; and
- to provide immediate guidance on the major pitfalls in the design of these systems and how they might be avoided.

The study has been restricted predominantly to office buildings in the UK. *Overseas examples need more study.*

1.2 State of the art: mixed mode design

1.2.1 STATE OF THE ART GENERALLY

The scoping study indicates that MM concepts could have an important role to play in the provision of cost-effective, adaptable, lower-energy, comfortable, future-proof buildings. It has found over sixty examples which have been built over the past twenty years, or are now under construction. Having initially been restricted to owner-occupiers and the public sector, a few examples are now emerging in the speculative market, where their adaptability should potentially be a strong selling point for both occupier and investor. *A market study is recommended, which asks owners and occupiers whether they would go MM again.*

1.2.2 STATE OF THE ART: CONTINGENCY DESIGNS

Contingency designs are relatively few, or perhaps relatively difficult to identify because most buildings are capable of modification as a last resort! We consider that the art of contingency design - where mechanical services can be added to a naturally-ventilated building (or vice-versa) - needs further development. For example, for the Body Shop to have the largely naturally-ventilated head office they wanted while meeting institutional demands, the building had to have ceiling void, rising duct and plant space to allow full VAV air-conditioning to be added. However, given the effectiveness of the passive systems, if this building were ever to be mechanically cooled or air-conditioned it is unlikely that VAV would now be chosen! Ideally it would be possible for services to be added quickly and easily in a variety of ways: by room, by floor, by wing, and so on. However, there is also the risk of the MM “scam”, where the developer leaves out essential features and the unwitting tenant picks up the tab. *We recommend an imaginative study of the architectural, structural and services engineering options for contingency designs, including methods for policing the more obvious scams.*

1.2.3 STATE OF THE ART: ZONED DESIGNS

Zoning occurs in many buildings anyway. However, the term is useful is raising awareness that a building does not need to be completely sealed and air-conditioned just because certain parts have to. *It could be useful to illustrate the opportunities for zoning with some case studies and worked examples.*

1.2.4 STATE OF THE ART: COMPLEMENTARY DESIGNS

The most common systems, and those of most interest to services engineers, have both natural and mechanical systems present and complementing each other. A good thing about this approach is that it can converge with a highly efficient design of an air-conditioned building and provide a transitional route between energy-dependent and more passive solutions. Earlier studies indicated that such systems could perform reasonably as far as the occupants were concerned, but sometimes their technical and energy performance was disappointing. The current study indicates that although there are some areas of progress (for instance in one or two “trickle-charged” buildings with continuously-ventilated hollow core slabs), in others shortcomings in technical and particularly in energy performance persist. *This requires urgent attention, both through further investigation and in the development of good practice guidance on how to include the extra mechanical services without losing the value of the low-energy building design.*

1.3 State of the art: mixed mode in use

1.3.1 CONTINGENCY DESIGNS IN USE

Contingency designs are relatively few. Some are successful as naturally-ventilated, and have required few if any additional services, vindicating this risk management approach. Going the other way, a few shallow-plan air-conditioned offices of the early 1970s (particularly those for local authorities) have reverted (or are considering reversion) to natural ventilation or MM. On the other hand, some have quickly had mechanical systems added which probably should have been there in the first place. We have also been warned by BREEAM surveyors that it is not unknown for developers of some buildings cynically to omit the necessary ventilation and cooling systems, to collect the natural ventilation and refrigerant avoidance credits, to promote the building spuriously as low-energy, and to pass on the costs of what are really essential systems to the tenant. Of course, there may be tax advantages to this.

We are beginning to hear of poor comfort votes in some recently completed buildings with advanced natural ventilation: particularly in the deeper plans and where there are non-traditional relationships between occupants and windows. Here we think that narrowing thresholds of discomfort - that well-known effect that requires environmental conditions in sealed buildings to be kept in a narrower range than in "free-running" ones - may be partly responsible. In these situations, MM strategies might have been more robust. *When these buildings are appraised, the origin of the problems and the potential for MM should be explored.*

1.3.2 ZONED DESIGNS IN USE

Zoning is most successfully done where the zoned parts are functionally different from the others. In spaces of similar appearance and use, local differences in servicing can lead to misunderstandings (where different behaviour is required depending upon exactly what is provided in the area) and jealousies (e.g: in hot weather if an area in which cooling is provided - perhaps to counter higher solar or internal gains - is noticeably more comfortable). This can lead to creeping, and perhaps inefficient, AC. *Caution needs to be raised about designs in which the servicing of ostensibly-similar spaces differs from place to place. In addition, it could be worth exploring how different systems could be integrated more seamlessly.*

1.3.3 COMPLEMENTARY DESIGNS IN USE

Complementary designs are the most common and reveal the widest range of successes and difficulties. Earlier BRECSU and EnREI studies showed that they could work very well, but that design and control problems could easily occur, leading to lower performance and higher energy use than anticipated, particularly the latter because in buildings with openable windows people are more tolerant of the former. At present largely anecdotal information from more recently-completed buildings suggests that, with a few notable exceptions, these problems are (if anything) are becoming more widespread. There are several reasons why this might be:

- i As low-energy design becomes more mainstream, it is attracting a wider range of people who may over-reach themselves or repeat old mistakes. Others may regard it as a technical fix and not re-think their approaches sufficiently.
- ii The earlier designs tended to be in fairly heavyweight shells. Some newer ones in are in lighter, more thermally responsive, less robust (and often less airtight) curtain-walled construction derived from their AC predecessors. They are designed less in response to the environment and so lean more heavily upon their mechanical systems.
- iii The earlier buildings were seen through from beginning-to-end by one designer. Responsibilities are now more split, e.g: with design-and-build and shell-and-core.
- iv Client requirements are more exacting and buildings are often more intensively used.
- v Management is more often outsourced, and may not take (or be contracted to take) ownership of unusual systems.
- vi New technology, including computer modelling, permits designers to envisage increasingly elaborate operating strategies which may not be realised in practice.
- vii Intense competition and fast-tracking makes it difficult to pay attention to critical detail.
- viii Occupant and management needs, habits and expectations are not well understood.

There is a great need for more research and for design guidance in this area, and the surveys suggest that there may be scope for slimming-down the mechanical ventilation component.

1.4 What are the main issues?

1.4.1 In the following sections, the problems will be related to the key objectives outlined in 1.1.2: Adaptable, manageable and cost-effective; more comfortable; and lower in energy use.

1.4.2 ADAPTABLE?
Few MM buildings have yet had to prove their adaptability. Partly this can be attributed to their their robustness: where windows can be opened, occupants complain less about shortfalls in mechanical systems; and vice-versa, so the tolerance margins are widened-out. *As with the contingency designs, we also think that there is scope for improvements in adaptability.*

1.4.3 MANAGEABLE?
For the more sophisticated systems, the equipment is not dissimilar to that in an air-conditioned building, though generally somewhat smaller and simpler, and sometimes without - or without much - refrigeration. Maintenance and fine-tuning requirements tend not to be as exacting owing to the simpler systems and wider tolerance margins, and some systems are very simple - for example with constant-volume, constant-temperature background ventilation. Operationally, however, some *changeover* systems can be quite complex, and have a tendency to default to *concurrent* operation (see 1.4.5). Maintenance and cleaning associated with the openable windows also has to be taken into account.

1.4.4 COST-EFFECTIVE?
MM buildings tend to cost up to 15% less per square metre than air-conditioned alternatives of a similar perceived quality standard, with a typical quoted level of 5% for buildings with extensive mechanical ventilation. Sometimes the planning or the need for access to windows may also reduce the usable area that can be fitted on the site, or the ratio of usable to nett internal area. *Since the capital cost margin can be quite small (except for naturally-ventilated contingency designs), the payoff really needs to come in occupant satisfaction, lower energy consumption and environmental impact, higher rental values, or lower costs in use - including environmental costs. More study of these is required.*

1.4.5 MORE COMFORTABLE?
The earlier studies indicated that MM buildings were usually perceived as more comfortable than similar ones with natural ventilation alone. In particular, air movement and peak temperatures in summer were better. In addition, the occupants were more *forgiving,* i.e: their general impression of comfort was higher than one would have anticipated by averaging their votes on individual aspects. This time round, the anecdotal message is more mixed, at least for the offices which did not have mechanical refrigeration: this may be partially a consequence of the hot 1995 summer. Other problems may however arise from lighter-weight envelopes and insufficiently well-controlled heat gains. There are also indications that in deeper-plan spaces and where individuals do not have good perceived control, people are less tolerant of elevated summertime temperatures than current assumptions suggest. However, a short, relatively hot period is also no reason to condemn a design: recent studies for BRECSU at the Open University suggest that on a year-round basis people may prefer a passive solution, even if summertime temperatures are occasionally high (but a passive solution with optional comfort cooling might be even better!). *We recommend more occupant surveys of perceived comfort, accompanied by physical measurements where appropriate. Comfort criteria may also need to be reviewed in relation to degree of control and proximity to windows.*

Centrally-activated system changeover can be problematic. For example, if a mechanical system springs into life, while on average people may be more comfortable, some may be inconvenienced by the change in local conditions and complain. After a while, management may then choose to select concurrent operation instead, as a simpler and more reliable strategy. People may also find it difficult to relate to a system which has seemingly no consistent logic. *Designers must be made aware that changeover systems often default to concurrent operation and take care when planning changeover strategies, which recently have tended to become increasingly elaborate. However, there is scope for more use of demand-activated and interlocked changeover systems, for example using interval timers and window switches.*

1.4.6 LOWER IN ENERGY USE?
In relation to natural ventilation, energy cost and CO_2 savings by controlled mechanical ventilation have often been claimed but seldom proved, particularly in the UK fuel economy with heating by gas - and this also applied to MM buildings. In relation to air-conditioning, MM buildings potentially offer reductions in energy consumption for fans, pumps and cooling. While the last two can often be proven, for fan consumption the picture is less clear. For many recent systems air volumes, specific fan power, and often hours of operation are relatively high, particularly if systems designed for occasional *changeover* use (eg: mechanical night ventilation) are operated *concurrently*, and particularly at high speed. *Great care is required to design mechanical ventilation systems for MM buildings which are both genuinely intrinsically low-energy and which can be operated to minimise avoidable waste. Guidance on this would be useful. Careful attention is also required to comfort, control and manageability of systems which have a variety of possible operating states, and for minimising the downside risk of wasteful operation. Energy audits of recent MM buildings are recommended, perhaps using the Office Assessment Method which was developed as part of an EnREI project and which is being used successfully in the current PROBE studies in Building Services - the CIBSE Journal.*

1.5 Scope of proposed guidance

1.5.1 MM has great potential in principle. However, it is not yet well-described or its features, strengths and limitations properly explored or understood by either the demand-side or the supply-side of the market. Now an increasing number of buildings are being constructed along these principles, we fear that it could easily get a bad name through gratuitous or well-meaning but misinformed responses, and by not living up to its aspirations. For example:

- *Contingency* design could be used as an excuse for a cheap cop-out in which the passive design measures are not throughly done and to which the mechanical systems, added quickly, were more expensive, less effective, less long-lasting and less-efficient than if they had been built-in to start with.
- *Complementary* designs may not deliver (and some are not delivering) their promises for comfort and particularly energy-efficiency.

1.5.2 There is a clear need for the proposed CIBSE Applications Manual, which would probably concentrate on *complementary* systems. Some work necessary to support this has already been outlined in the italic sections above. We recommend that an early draft is written quickly based upon current knowledge. This can then be fleshed-out with studies as necessary under the following headings:

- A survey of the attitudes of existing owners and occupiers to MM systems.
- Occupant questionnaire surveys on comfort, control and usability.
- Energy surveys, with lessons for future design and management.
- More detailed environment and comfort surveys, if deemed appropriate.
- An options study for adaptable designs, including contingency designs.
- Possibly some simple models of cost, energy and risk.

1.5.3 In addition, we recommend another well-illustrated document which aims to develop the concepts and improve everyone's awareness of them. It should not over-sell the mixed mode route but instead help those who are already trying to do a better job and to identify common pitfalls. It should be readable by all the parties involved: from clients, through property, building and facilities management professionals, to the end-user. It could:

- explain the MM route, its varieties, and their likely opportunities and pitfalls;
- develop the agenda for adaptable *contingency* designs;
- set down and develop the attributes of *complementary* design, and
- identify the areas requiring careful attention to strategy and to detail to help to enhance the good features of effectiveness. efficiency and usability and adaptability and to minimise the risk of failure.

In a sentence, the key message would seem to be to aim for excellence in robust integration, with features that add functionality, not complication.

2 INTRODUCTION

2.1 CLASSIFICATION OF BUILDINGS BY VENTILATION TYPE

Buildings are frequently classified by their predominant means of ventilation and cooling: naturally-ventilated (NV), mechanically-ventilated (MV), or air-conditioned (AC). But buildings often contain a variety of HVAC services; with some MV in NV buildings, if only in toilets; mechanical and natural ventilation combined in supply-only or extract-only systems. Most AC buildings also have some NV and MV areas. Many “AC” buildings are not AC in the strict sense of the term, but merely comfort-cooled - though this can be perfectly appropriate.

2.2 MIXED-MODE DESIGNS

This report reviews mixed-mode (MM) designs, which deliberately set out to combine natural and mechanical systems in the same space, though not necessarily at the same time. MM is a conceptual approach, not just an engineering solution. It can help to meet owners’ and occupiers’ requirements for adaptability in an uncertain world, and avoid wasting money and energy on buying or running inappropriate and unnecessary environmental services. From the environmental point of view, MM offers a prospect of more robust, adaptable, manageable, long-lived, and cost-effective buildings; with fewer in-use emissions of greenhouse gases and pollutants, and improved occupant satisfaction. While there is a rapidly-increasing interest in MM, at present it is still seen as somewhat unusual. However, just as we routinely mix natural and artificial lighting without a second thought, perhaps MM should be seen as the normal way of doing things?

MM principles can apply to all building types. However, the prime emphasis here is on offices: in which there is already considerable interest and experience and the greatest immediate opportunities. Commercial and public sector offices account for some 12% of the UK’s non-domestic floorspace, 17% of commercial and public sector CO_2 emissions, and 5% of all buildings-related CO_2 emissions [16]. MM principles are also relevant to a similar (but probably less energy-intensive) amount of office-like space in sectors including industry, education, transport, laboratories, retailing and public services. In all sectors, this office-like space is also increasing as more activities are undertaken on desk-top computers, while some traditional office blocks and other building types are becoming redundant.

2.3 THE OFFICE MARKET

Opportunities for mechanical ventilation alone in UK offices have been limited (though they are now increasing with modern techniques of heat storage etc.); and this has contributed to a sharp division of this predominantly speculative market into NV and AC buildings. Indeed, patterns of institutional investment can be seen as having fostered the development of an increasingly limited range of building types [22]. Since the early 1980s, air-conditioning has been the institutional norm for the larger and more prestigious office buildings in the UK (at least in the better locations where rental values can stand it) and in spite of some setbacks such as building-related sickness. The very familiarity of the now standard office block provides a comfortable sense of security for investors and occupiers alike [23].

2.4 EXEMPLARS AND OPPORTUNITIES

Over the past twenty years, some owner-occupiers have been more adventurous and prepared to build MM offices. 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 to institutional investors as “pre-lets” and lease them back. To improve marketability, the buildings must then conform with market standards- although pre-lets have more scope for variation than in the purely speculative product. While there is now wider interest in MM designs, the market is still understandably cautious about what many regard as somewhat nebulous products with an uncertain value and which may not sell; may not work (or not without making unreasonable demands on occupants and management); may lack flexibility; and may not even meet their environmental aspirations. Nevertheless, we see great opportunities for looser-fit, more generic, less specialised buildings which can readily be adapted to the needs of different occupants, activities, and even sometimes sectors.

2.5 FUTURE ENVIRONMENTAL TRENDS

The environmental imperative and trends in public attitudes make serious professional consideration of passive, low-energy solutions essential. For example, the draft CIBSE Design and Applications Manual on Natural Ventilation in Non-domestic Buildings [1, page 1.11], recommends natural ventilation as the default design strategy, followed by mixed-mode, with sealed buildings with full air-conditioning as the last resort. The Air Infiltration and Ventilation Centre [103] states that all buildings which are likely to need active cooling should adopt MM design guidelines.

2.6 FUTURE BUSINESS TRENDS

At first perhaps surprisingly, the business imperative also points in a similar direction: to cost-effective flexibility; a greater emphasis on user needs and environmental impact; and lowering costs while adding value and behaving more responsibly. For instance, preliminary outputs [7] from the BRE/DEGW study of New Environments for Working (NEW) indicate that medium-depth buildings are best suited to many aspects for tomorrow's changing workplace. The suggested 15 metres glass-to-glass distance is near the upper limit for natural ventilation (particularly if ceiling heights are constrained and there is a need for cellular offices) but fertile territory for MM options. In the context of high uncertainty, high variability, and occupant preferences, the NEW study also sees MM ventilation and cooling systems as often being the most appropriate in principle, although sometimes requiring technical innovation.

2.7 PURPOSE OF THIS REPORT

The report is intended to put some flesh on the bones of MM strategies, and to set the scene for a possible CIBSE Applications Manual on mixed-mode design which will complement the new one on Natural Ventilation [1]. But not only engineers need information and advice. This report should also pave the way for related publications which can help to improve professional and market awareness of the strengths (and weaknesses) of MM approaches; to identify any proven techniques and technologies; and to discuss possible avenues for conceptual and technical innovations of a relatively straightforward nature.

3 STRUCTURE OF THIS REPORT

This report is in four main parts, together with conclusions, references and appendices.

3.1 PART A — MIXED MODE IN THEORY

Chapter A1 outlines the reasons for wishing to take this approach, and the potential strengths and weaknesses of MM in relation to the NV and AC alternatives. Chapter A2 discusses definitions of MM, both generally, in classifying its different aspects and varieties, and in relation to the features adopted in completed MM buildings. More details can be found in Appendix X. Chapter A3 discusses strategies and their selection, and includes strategic briefing, an outline of the purposes and methods of ventilation and cooling, and a selection chart.

3.2 PART B — MIXED MODE IN PRACTICE

After an introduction, Chapter B2 reviews the features of some existing MM buildings, and identifies some common characteristics and features of particular interest. Some aspects of the buildings are explored further in Chapter B3 and their engineering systems in B4. Chapter B5 outlines some problems which commonly seem to occur and that new designs should seek to guard against. The concluding Chapter B6 sets down some major themes which are thought to require dissemination or guidance.

3.3 PART C — PRINCIPLES OF DESIGN AND MANAGEMENT

This explores issues thought to be critical to any design guidance. The introduction is followed by an outline of good practice design principles which aim to combine good environmental performance with adaptability and occupant satisfaction. Chapters C3, C4 and C5 then consider the critical technical issues of window design, mechanical services integration, and their control in relation to occupant comfort. The concluding Chapter C6 discusses operation, management and maintenance: all critical to the success of these buildings and systems, which must be designed to suit management and occupant needs and to avoid unmanageable complexity.

3.4 PART D — NON-DESIGN ISSUES

Many reasons for choosing (or avoiding!) MM solutions are not related to their design potential but to possible opportunities for (and obstacles to) their uptake. These include marketability, cost-effectiveness, energy and environmental benefits, and health issues. Following an introduction, the four main chapters discuss each of these in turn.

3.5 PART E — NEXT STEPS

This summarises the various arguments, and suggests future work necessary to obtain more information, to provide incentives and guidance, and to develop a CIBSE Applications Manual on MM design, or some aspects of it.

A1 STRATEGIC OPPORTUNITIES, STRENGTHS AND WEAKNESSES

A1.1 ORIGINS OF MIXED-MODE

The term mixed-mode (MM) was coined to classify buildings reviewed in BRECSU office case studies which were neither predominantly naturally-ventilated nor fully air-conditioned. It was first used in public in 1989 [4], though the buildings themselves pre-date a term which had to be coined to describe them! Some of these hybrids had quality features normally associated with prestige AC offices, but were cheaper (or certainly no more expensive) to buy and to run, used less energy with fewer emissions, and gave similar or better occupant satisfaction. Some NV buildings had also evolved into MM of a kind, adding comfort cooling and other systems while keeping their openable windows. The initial definition [2] was *a building with complementary systems of ventilation and cooling available, frequently background mechanical ventilation at low volume (typically one or two air-changes per hour, sometimes with chilling), together with openable windows*. A more detailed categorisation, developed by Max Fordham and Partners (MFP) [3], is discussed in Chapter A2 and Appendix X.

A1.2 BEYOND A SINGLE CHOICE

At a very early stage, irreversible decisions are often made to seal and air-condition an office building because NV is (or is seen to be) unable to meet all the design requirements or contingencies, or because AC will be (or is predicted to be) a better investment for the site regardless of technical need. MM strategies can potentially offer a wide range of benefits by creating a “bridge” between NV and AC, avoiding such all-or-nothing choices and offering other advantages. Indeed, one might reasonably expect a blend of natural and mechanical systems to be more appropriate to many requirements than options at the far ends of the scale.

A1.3 AN UNKNOWN QUANTITY

In spite of this, MM is still a somewhat unknown quantity. Until design standards and strategic, technical and managerial solutions are better defined, it could be a mixed blessing. For example nobody may quite know what is what; facilities staff may need more engineering competence than is reasonable; adaptation - although straightforward in principle - could prove expensive and its results uncertain; and alternative systems could clash, wasting energy and not necessarily improving comfort. All these will also tend to lower a building’s market value.

A1.4 COMPARISON OF POTENTIAL STRENGTHS AND WEAKNESSES

This report attempts to present a balanced view and to identify ways of enhancing good points whilst taking account of and attempting to minimise potential problems and failure paths. Table A1 reviews some general features, with their strengths, weaknesses, and other comments, for the seven potential beneficiaries outlined below. Other attributes will be assessed after MM principles and technologies have been explored in more detail.

1. *For the developer*. A cost-effective (though not normally lowest-cost) approach with potential to appeal to a wide range of customers. In particular it could give the “flexibility” that is often an important selling point of full AC, at lower cost and with less energy consumption and energy-dependency. AC’s promise of flexibility is not always delivered in practice: tenants often have to do more re-engineering than expected, and then spend more time and money on maintenance and management than they feel is reasonable or often wish to provide [6]. However, the complexity, and not specifically the AC may be the problem: designers of MM schemes must always be acutely aware of this pitfall.

2. *For the investor*. By being more readily adaptable to a range of occupant requirements and future scenarios, MM could potentially be a better short- and long-term investment.

3 *For the designer.* MM could make it easier to provide buildings for users with unknown needs - and not only for speculative buildings: many organisations and the uses they make of buildings are changing fast. Technically MM may also be able to stop a building which can't quite work with natural ventilation - for example with too deep a plan, needing some additional cooling or heat removal, or having a noisy road too near one facade, becoming fully air-conditioned by default. By combining natural ventilation with mechanical systems MM could offer the best of both worlds......or perhaps the worst!

4 *For the occupier.* MM could potentially meet the requirements of some, if not most, occupiers more effectively, more straightforwardly, and at lower cost than sealed, air-conditioned buildings. It may also fit business strategic thinking in an increasingly uncertain world, by hedging bets and demonstrating concern for occupants, the environment and "no-frills" waste avoidance.

5 *For the building manager.* MM buildings may be potentially more robust, more adaptable, and have fewer costs, maintenance and management burdens. However, there are new skills to be learned.

6 *For the individual occupant.* In surveys [e.g: 89], occupants often say that they like to have openable windows. Where they have them (and provided the windows open onto a reasonable environment) occupants also seem to be more accepting of numerous aspects of the internal environment, including summertime temperatures, noise and air quality. However, recent studies [26, 27] indicate that the benefits of natural ventilation are often perceived primarily by those sitting next to the windows. Mixed-mode designs promise some of the benefits of openable windows in an internal environment which can be objectively better than would be possible with natural ventilation alone.

7 *For the environment.* Potentially longer-lived buildings with less energy consumption, less risk of premature obsolescence, and sometimes possibly including modular plant which could be sold and re-used if it was no longer required. A smooth transition to more sustainable buildings, but with less of a risk of non-performance in today's harsh business environment.

A1.5 MAJOR THEMES

Strong themes which come through in Table A1 include a need for:

- Clear strategic approaches.
- Systems which complement each other rather than clash.
- Manageable systems which seek to avoid unnecessary complication.
- Avoiding wasteful energy performance, for example by taking care that systems are not too powerful, inefficient, on too much, or fight each other.
- Improving controls: for occupants, for management, and for effective energy-efficient operation.
- Clearer standards and generic exemplars.
- For some types of MM building, trying to reduce the plant which is a permanent (or semi-permanent) part of the building and adding components when and where necessary in a modular form which can be readily adapted and exchanged.

For all varieties of MM, simple and ingenious methods of providing the required adaptability could provide inspiration for designers and their clients. Some theoretical options are outlined in reference [11], but we think that the concepts need to be developed, clarified and illustrated.

TABLE A1.1 Page 1		**MIXED-MODE SYSTEMS: SOME POTENTIAL STRENGTHS AND WEAKNESSES**		
	ITEM	***POTENTIAL STRENGTHS***	***WEAKNESSES***	***COMMENTS***
1	***For the developer***			
1.1	Widen the potential market by providing more adaptable, generic buildings.	Building lettable (faster?) to a broader range of tenants.	Some tenants may have to do more to get into the building.	If at all possible, upgrade options should be simple and readily available.
1.2	Costs less than an air-conditioned building (but more than a naturally-ventilated one): this needs good value engineering.	More money can be spent on passive fabric with long term value, less on obsolescent services.	May get less lettable area on a site. Openable windows may be extra cost if air-conditioning is needed	DL&E and Dutch cost data suggests that more is spent per sq m on sealed facades than on facades with openable windows!
1.3	Extension of "shell and core" concept. Adaptable to meet changing needs.	You get (and pay for) only what you need.	Late enhancements may be more necessary or more expensive.	Minimise complexity by having a clear design approach and ready adaptability.
2	***For the investor***			
2.1	Better long-term investment value.	A. Helps to avoid obsolescence.	Sound decisions have to be made.	No clear examplars yet.
		B. Can alter servicing mode easily	Uncertainty. Low market awareness.	Greater familiarity required with options.
		C. Re-fits can be done faster.	More tinkering may be required.	More standardisation could be helpful.
			Promotes a throw-away culture?	Needs a secondhand market!
3	***For the designer***			
3.1	Helps to deal with uncertainties in briefs for unknown clients or changing needs.	More detailed requirements and decisions can be left to the occupier.	Clear strategic thinking is necessary to get the fundamentals right. Who will pay for the extra design time?	Not a cop-out! Careful thought is required on design and management responsibilities and the expectations of users.
3.2	Extends the limits of natural ventilation.	Permits deeper and more complex plans with greater "flexibility".	Occupants distant from windows feel less comfortable than those nearby.	Hybrids may improve the cost-effectiveness and plot ratio of non air-conditioned buildings.
3.3	Permits the use of openable windows in mechanically-serviced buildings.	Solutions can be more appropriate to the context. May reduce costs.	Potential confusion, antagonistic operation, and complication.	Clear standards and control strategies required to avoid unmanageable complexity.
3.4	Can avoid unnecessary use of mechanical systems, in space and in time.	Less to go wrong. Potential cost, energy and maintenance savings.	Energy may not be saved if systems are inefficient or poorly-managed.	Systems must be designed and operated to minimise potential conflicts and waste.
3.5	Air quality can be controlled mechanically with low-volume background ventilation.	A. Low power mechanical systems possible if windows are openable.	Too much window opening may undermine the mechanical system.	Systems must be complementary, and must not "fight" each other too much.
		B. Can help avoid winter draughts.	Energy consumption and emissions may increase-though they need not.	Also able to remove local heat and pollutants.
		C. Can remove local	Systems may run too much.	Zoning and control becomes important.
3.6	Can add humidity control, heat recovery and cooling to background mech vent.	Not readily possible with natural ventilation alone.	Openable windows may reduce or undermine this effect.	Winter heat recovery and humidification may be OK. More clashes likely in summer.
4	***For the occupying organisation***			
4.1	Doesn't pay for what it doesn't need.	Suits current "lean and fit", no-frills business cultures.	Exploiting adaptability potential may require more (or different) skills.	Potentially promising but strategies need to be clearly thought through.
4.2	Services are innately adaptable.	Potential to tailor to needs at lower capital and energy cost.	Adaptation may be more expensive for some than upfront investment.	Depends on need and how well it is done. Some standardisation is desirable.
4.3	May be fiscal advantages.	Supplementary relocatable services may be tax-deductible business plant rather than building elements.	Danger that this might discourage capital investment and bias to short-life, low-efficiency solutions.	Depends on tax rules. Depends on efficiency, control and operational standards adopted.
4.4	Easier to dispose of or to sublet.	Attracts a wider range of new tenants.	May require investment in services modifications.	Could be a potentially important strength.

TABLE A1.1 Page 2		MIXED-MODE SYSTEMS: SOME POTENTIAL STRENGTHS AND WEAKNESSES		
	ITEM	***POTENTIAL STRENGTHS***	***WEAKNESSES***	***COMMENTS***
5	***For the building manager***			
5.1	No need to look after systems which are not essential to the building's function.	Less time spent on routine, more to focus on genuine needs.	If systems are less standard, they may require more knowledge and insight to look after.	Appropriate facilities management and operational strategies must be clearly established, with suitable support.
5.2	Habitability of the building is less tightly-coupled to minute-to-minute mechanical services performance.	If windows are openable, occasional shortcomings are less likely to grow into urgent management problems.	A. The potential variety of equipment and operating modes may be complicated and confusing.	Need to keep technical, control and management solutions simple, at least as the default state for the less sophisticated user.
			B. Openable windows introduce dirt and may increase cleaning costs.	The extent depends how much the windows need to be opened.
5.3	More robust, less fragile. Potential to cope more easily with breakdowns and the unexpected.	A. More likely to fail "soft", giving more time to put things right, for both short- and longer-term issues.	May have less power in immediate reserve. Management must be sympathetic to making changes.	EnREI studies by BUS confirm the potential of MM buildings to fail soft. But they must also be manageable, and well-managed.
		B. Potentially less to go wrong and less mechanical plant to maintain.	Variety of equipment may be problematic.	Probably cheaper than air-conditioning plant maintenance, but not always.
6	***For the individual and group***			
6.1	Most occupants prefer openable windows, even if they don't use them much.	Occupants are more tolerant of raised summertime temperatures than in sealed buildings.	The margin is quite small. Windows need to have a reasonable outlook, work well, and be easy to operate.	Benefits diminish as spaces become deeper and occupants lose outside awareness and perceived or actual control of windows.
6.2	Occupants like to adjust windows and blinds (but not too often).	This improves satisfaction by permitting rapid alleviation of discomfort when it occurs.	A. Access routes to windows may reduce efficiency of space use, and if blocked may reduce comfort.	Restrictions on furniture layout and resultant loss in usable area may be substantial (perhaps about 10%?).
			B. Even if windows are accessible, those not beside them often hesitate to operate them, or opinions may differ. Result: paralysis.	Workgroups may constrain environmental preferences. To improve satisfaction of inboard workers, consider remote control of upper windows and blinds.
6.3	More chance of putting local problems right by fine-tuning or local alterations.	Solutions can be tailored to the specific requirement.	Not all organisations will spare the time and money.	Switchable and/or modular relocatable solutions permit more rapid response.
7	***For the environment***			
7.1	More sustainable design with a greener image	Reflects well upon all parties.	Unfamiliar territory. Benefits may sometimes be illusory.	Needs clear strategies, plus design and management standards and benchmarks.
7.2	Potential to reduce energy consumption and related pollutant emissions.	Mechanical systems can be lower-powered and/or run for fewer hours.	Reductions may not materialise if system or operation is inefficient.	Care must be taking to design systems for economy and to prevent wasteful operation.
7.3	Potentially a longer building life with less premature obsolescence and scrapping.	Provided that the strategy is right.	Ready adaptability might encourage early scrapping of some elements (but these may be a relatively small part of the whole).	Requires careful thought, but there may be interesting and useful generic solutions.
7.4	Potential to use modular items of plant, which can be redeployed or sold after use.	Offers rapid, tailored response to changing needs.	But needs strategy, standardisation and an active secondhand market.	Scope for innovation in packaging existing (and new) products in exchangeable form?

A2 MIXED MODE DEFINITIONS AND CLASSIFICATIONS

A2.1 Introduction

A2.1.1THE VARIETY OF MIXED MODE DESIGNS

MM designs can combine natural ventilation with a wide range of mechanical ventilation and cooling systems, potential or actual. At one end of the scale there may be no mechanical systems at all, but merely strategic provision for adding them in one or more ways, for part or all of the building. At the other end, a building may be fully AC, but planned so that in different circumstances all or part could function with less (and possibly even no) mechanical assistance. An enormous variety of mechanical services may be installed and combined with natural ventilation in many ways - in space, in time, working together, working alternately, and so on.

A2.1.2IS CLASSIFICATION WORTHWHILE?

Given this potential variety, to attempt a detailed classification may be troublesome. In addition, key features of MM are adaptability and opportunism, so buildings (or parts of them) may alter in classification as they evolve in operation and use. Should the term MM apply to all buildings which incorporate more than one ventilation and cooling system? Or would this debase the currency? Might it be better to talk about MM *systems,* which combine natural and mechanical ventilation and cooling systems (or system options) in the same space? The MM idea is not only for engineers, it can also affect the whole approach to building procurement, marketing, design and management. It could be an integral part of the response to an increasingly uncertain world in which buildings can no longer pretend to be precise solutions to carefully-measured and unchanging briefs. To paraphrase a comment on education for business by Handy [17, page 193] - perhaps MM systems should be seen as “starter kits which can help the occupants to work out their own solutions to their own predicaments”.

A2.1.3THE DESIRABILITY OF SOME CLASSIFICATION

People find it useful to consider buildings (or parts of them) in the major groupings of NV, AC, and to a lesser extent MV. In the property market, these terms have associations with not only the ventilation and cooling system, but with a whole group of features which tend to be associated with the mental image of a specific type of building - and which affect its market value. The general term is qualified where necessary, e.g: partially AC. Those really interested can find out more if they wish (for example: VAV with LPHW perimeter heating, gas-fired steam humidification, maximum eight air-changes per hour, allowance for 25 W/m^2 equipment heat gains, and so on), but at a first pass (except perhaps for the air-conditioning type) these details are much less important.

On balance, it appears to be very useful to have in common parlance *a single all-embracing term* such as MM (and it is probably too late to change it) to describe buildings which combine openable windows with mechanical ventilation and cooling systems, and which are more readily adaptable (though often less powerful, at least in their basic form) than the traditional exemplars. Given that that the market uses only two or three terms at the moment, seeking to add more than one looks far too ambitious! More detail can come in the small print.

For marketability, the general term would also be an umbrella for a group of desirable attributes (as outlined in Chapter A1), and not just an approach to ventilation and cooling services. Indeed one can argue [25] that MM should become the normal state of things (as for lighting), with NV and particularly full AC the special cases! MM attributes could be promoted not as the middle ground but as superior - at least in the right circumstances.

A2.1.4APPROACH TO A POSSIBLE CLASSIFICATION

Section A2.2 outlines the existing classification of MM buildings by Max Fordham & Partners (MFP) [3]. In Sections A2.3, known MM buildings are reviewed in relation to these definitions, considering in particular their design intentions and features, and any major physical and operational changes which have occurred in use. Section A4 then puts forward some propositions for discussion. More details can be found in Appendix X.

A2.2 MFP's mixed-mode definitions and classifications

A2.1 ORIGIN OF THE DEFINITIONS

A2.1.1 The most detailed classification of MM buildings: *Contingency*, *Concurrent*, *Changeover* and *Zoned* was developed by Max Fordham & Partners (MFP) under the EnREI programme [3]. These definitions are outlined below, with some comments on their interpretation and implementation. Other definitions are discussed in Appendix X.

A2.2.2 *CONTINGENCY*

In its most common form, *contingency* design is a building designed to be naturally-ventilated (for example along the lines discussed in the CIBSE Applications Manual [1]), but which also has a clear contingency plan (or plans) for adding mechanical ventilation and/or cooling if this proves to be necessary. At the opposite end of the scale, a sealed[1] air-conditioned building may have the potential to revert to a less energy-dependent form of operation, for example if planned for natural ventilation (and having suitable openable windows etc. - even if initially they are locked shut), or some form of *concurrent* or *changeover* operation. Where the initial aim is to rely entirely upon natural ventilation, very careful attention to passive measures and to heat gain avoidance will be necessary, and window design becomes critical.

A2.2.3 *CONCURRENT*

This is the commonest form of hybrid, in which mechanical ventilation - with or without cooling - operates in parallel with openable windows. Often the mechanical system suffices, controlling draughts and air quality and removing heat, but people can open the windows if they want to. The systems need to be complementary, not antagonistic. Site studies however suggest that mechanical systems are often too powerful, not very efficient, and run much more than necessary and than the designers anticipated. Guidance material would help to identify some of the reasons for this, and permit some of the problems to be identified and avoided.

A2.2.4 *CHANGEOVER*

Natural and mechanical systems are available and used as alternatives according to need, but do not normally operate at the same time. Some examples include:

- *Seasonal changeover,* for example where windows are openable in mild weather but locked shut in winter, when mechanical ventilation is used to meet required air quality standards, avoid draughts and possibly save energy by using heat recovery.
- *Night cooling,* with natural ventilation during the day, and mechanical at night to remove excess heat built up in the fabric. This is useful where windows cannot be left open, or where air is passed over the structure to enhance heat storage effects.
- *Local changeover,* with window detectors to switch off nearby air-conditioning or comfort cooling units when the window is opened.

In practice it can be difficult to implement centrally-managed changeover design intentions reliably, owing to their complexity; an absence of input information to make an informed choice; poor or non-intuitive user interfaces; or adverse occupant reactions to systems which change capriciously (at least to them) and trigger some irritation to which they had adapted in the former operating mode - for example by moving their desk. Consequently changeover systems frequently default to *concurrent* operation, usually with increased energy consumption and sometimes with worse performance. The risk of such difficulties may be rising as progressively more complex operating strategies are validated by computer models.

A2.2.5 *ZONED: with different services in different parts of the building:* for example comfort cooling locally for hot spots (probably a special case of *contingency* design), or in parts of the building (say) with a deeper plan, high solar gains or limited opportunities for natural ventilation. However, such variations in the servicing of nearby and operationally similar spaces in the same building causes problems for users: careful study and guidance is essential. Another variety of zoning is where services in special areas (eg: restaurants, computer suites, meeting rooms, swimming pools and toilets) differ from those in other parts of the building - but since this is perfectly normal it may not be helpful to classify this as MM.

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1 Perhaps a misnomer: recent BRE and BSRIA pressure tests indicate that some recent "sealed" air-conditioned offices in the UK have higher air-infiltration rates than many naturally-ventilated ones!

A2.3 Application of the MFP classifications to some completed MM buildings

A2.3.1 THE BUILDINGS CONSIDERED AND THEIR KEY FEATURES

Table B1 (see Chapter B1) lists MM buildings previously visited by WBA and Table B2 others - built or under construction - which have been described in the technical press. The two tables include their design intentions classified into the four MFP categories; mechanical ventilation rates in air-changes per hour (ac/h) where appropriate; air supply positions; predominant ceiling types (exposed, suspended, or variable - i.e: some of each); and other comments. For the buildings visited, Table B1 also includes notes on the operation and performance in use of the HVAC systems (including the natural ventilation element) in practice, including any changes made.

A2.3.2 CATEGORISATION OF THE BUILDINGS REVIEWED

Key points on categorisation include:

1. Many buildings fall into more than one category, though a single category usually predominates.

2. By far the most common design category is *concurrent*. It will clearly need the most attention, probably as the prime focus of the proposed CIBSE Applications Manual.

3. Only a few buildings were predominantly *contingency* designs. The Body Shop [10] is the clearest and best-known example: designed so that conventional (for the time) VAV air conditioning could be added if necessary. Several others (in fact, nearly all with air handling units) had contingency features on a broader BRECSU definition which includes the potential to add cooling coils: however, we have only assigned this feature where the intention was explicit, or if they had some chilling already, which could have been extended easily.

4. Salford Civic Offices - an early 1970s shallow-plan AC office was designed so that its AC could be removed if necessary at some future date. Its centre-pivot windows (with mid-pane venetian blinds) were openable not only for cleaning but as *contingency* provision. Now the AC is due for replacement they are considering whether to omit it, and in an EnREI study [15] Arup R&D found this to be feasible. The windows were initially locked but were then released following complaints, creating an ad hoc *concurrent* solution which the staff preferred, partly because the AC was a changeover induction system which did not cope well with mild and fluctuating weather conditions. Several other offices have also reverted to *contingency*, *concurrent* or *changeover* operation following removal of AC.

5. Not including the normal differences in reception areas, toilets, loading areas etc., more than half the buildings were *zoned* with different types of services in different parts of them. The entry *"yes"* identifies physically similar areas of office-like space which had different servicing; for example with VAV summer cooling installed only on the solar-exposed facades at Hereford and Worcester County Hall[19], or mechanical ventilation to the offices around the atrium at Policy Studies Institute [18]. The entry *"local"* means that the zones were for special areas such as restaurants, computer rooms and conference/ training rooms, which would usually have been serviced differently anyway.

6. *Changeover* operation was most commonly used for mechanical night cooling and for chilling in hot weather (using supply air, fan coils or chilled panels). In some buildings visited - for example Hereford and Worcester County HQ and Refuge House [20] - the seasonal *changeover* arrangements planned by the designers had often been simplified in practice into *concurrent* operation, both for greater ease of management and to avoid disturbing or confusing occupants. We think that similar operational changes could well have occurred in some of the newer buildings.

A2.4 Conclusions on definitions

A2.4.1OVERVIEW

Combining natural and mechanical ventilation and cooling systems is a useful concept and one which we expect to become increasingly widespread. The term *mixed mode* is already quite well entrenched and we feel it should remain all-embracing and not be restricted to particular types of solution. For a more detailed classification, the MFP system has been reviewed and we think would benefit from some minor alterations. More detailed generic classifications do not seem to be helpful: it would be better to give technical details of the systems.

A2.4.2GENERAL OBJECTIVES

One thing missing from earlier definitions was a statement of general objectives. We think that all MM buildings and systems will comply with at least one and often all of the following:

OBJECTIVE 1 Longer-lived buildings which can be adapted to changing requirements, standards and priorities, and serviced to meet occupiers' real needs whilst avoiding wasteful over-provision, unnecessary capital and running costs, or burdens for management.

OBJECTIVE 2 Better occupant satisfaction, by combining the perceived advantages of openable windows with any mechanical servicing necessary to provide suitable levels of health, safety and comfort.

OBJECTIVE 3 Lower energy use and the associated greenhouse gas and pollutant emissions through avoiding the unnecessary provision and operation of mechanical systems at times and in places where natural ventilation could achieve the task more efficiently.

A2.4.3DIFFERENT CLASSIFICATIONS

The MFP classification: *Zoned, Contingency, Concurrent* and *Changeover* has worked well, but some shortcomings have been exposed. A classification system with four separate facets would be theoretically more appropriate (see Appendix X), and leads to the following general definition: *Mixed-mode is an approach to ventilating and cooling in which natural ventilation (normally using openable windows) and mechanical ventilation and/or cooling systems are deliberately combined:*

1 *For the* whole building *or for* parts *of it.*
2 Actually *(with both systems present) or* potentially *(in building designed for easy addition, removal or alteration of part or all of the mechanical systems).*
3 *As* complementary *or* mutually exclusive *alternatives.*
4 *If complementary,* by operating together *or* as alternatives**.**

A2.4.4RECOMMENDED SIMPLE CLASSIFICATION

In spite of the above, more detailed classification does not seem worthwhile: it would be better to add specific technical details than to seek an elaborate all-purpose classification. We therefore suggest small alterations to the MFP definitions, as outlined below.

Strategically, we suggest the options of *zoned, contingency and complementary.*
Operating modes for *complementary* systems can then be broadly classified as either:

- *Concurrent,* where openable windows and mechanical systems operate together.
- *Changeover,* where the systems may operate in rapid succession but not normally together, except by default.
- *Alternate,* where a choice, once made (say to close the windows and operate full air-conditioning with humidity control) persists for a long time.

More complex strategies may include combinations of the above. More detailed descriptions can then be provided as appropriate, for example say seasonal changeover with controlled mechanical ventilation in winter, mechanical ventilation with night and comfort cooling in hot weather, and openable windows at other times. Further description of strategic and detailed engineering options will be considered later.

In colloquial terms, however the existing MFP definitions can still be used.

A3 SELECTING MIXED MODE STRATEGIES

A3.1 A strategic flowchart

A3.1.1 THE FLOWCHART

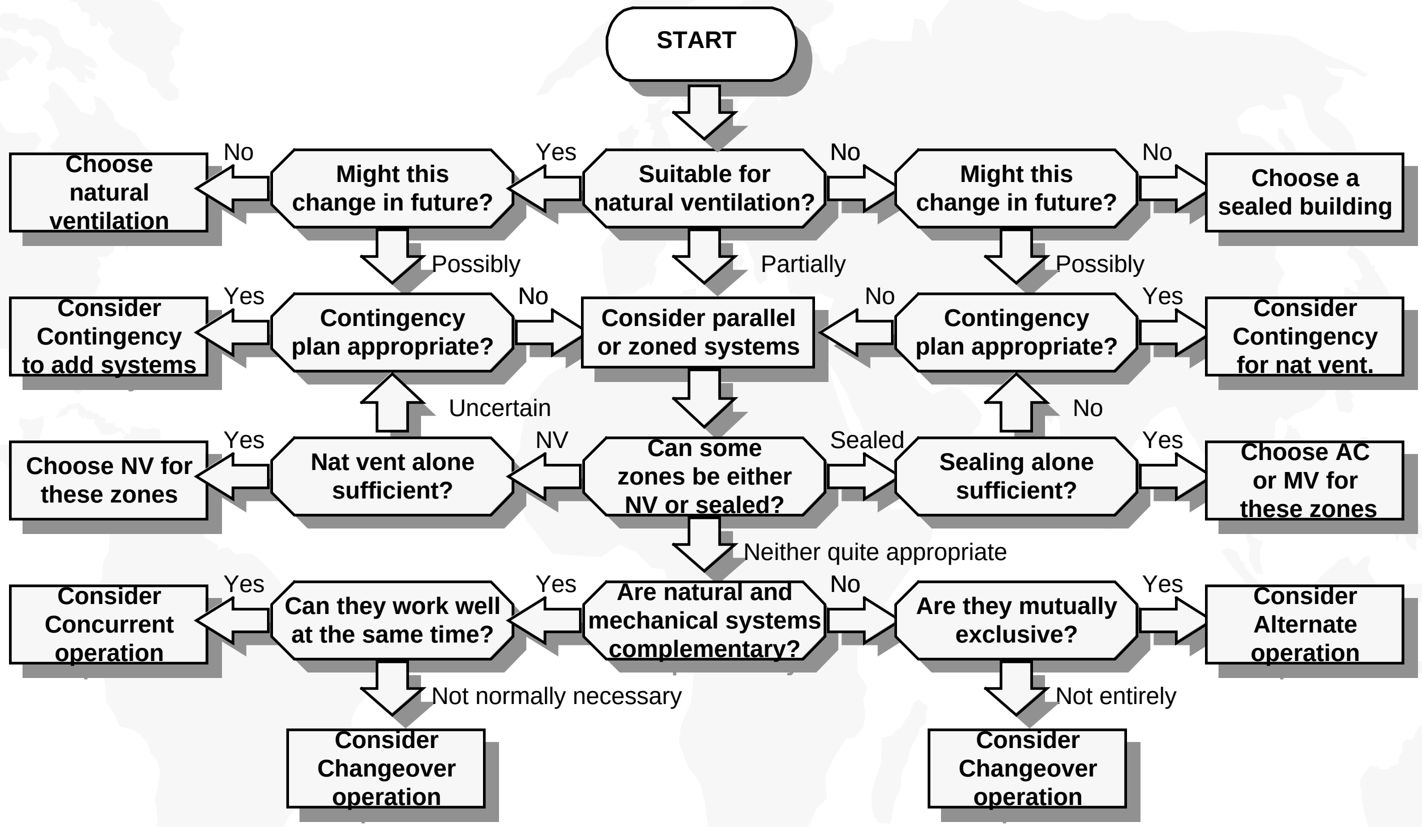
Figure A3.1 is a flowchart which is intended to indicate the appropriate mode of ventilation and cooling for a building or for a zone, using the classification system discussed in Section A2.4.4. The flowchart assumes that the suitability of the building for natural ventilation has already been reviewed, for example using the procedures in the CIBSE Design and Application Guide for Natural Ventilation [1], and particularly its figure 19. It also includes - at least in a rudimentary form - choices both for the building as a whole and for the zones within it.

A3.1.2 DEVELOPING THE OPTIONS

Under these headings, however, there is a wide range of options and possibilities, and it soon gets difficult to separate principles from practicalities. Ventilation and cooling have a variety of different purposes, and these can be met by a variety of different technologies. We therefore now turn to outlining the purposes of ventilation and cooling, together with some methods.

RESERVED FOR FIGURE A3.1

FIGURE A3.1 Mixed Mode Selection Chart



A3.2 Purposes and methods of ventilation

A3.2.1FIVE MAIN PURPOSES OF VENTILATION
Ventilation has five main purposes, outlined below together with an indication of the normal range of ventilation rates:

V1 *To provide sufficient "background" ventilation for air quality and odour control.* Today's good practice in an office is typically 10 litres/second per person [24], though this may be increased for smoking, crowded occupancies, or where there are additional sources of pollution. For a typical occupation density of 14 m^2/person [24] and a ceiling height of 2.7 metres, this equates to about one air change per hour (ac/h). For "minimum fresh air" mechanical systems a figure of about 2 ac/h is often used, probably because this permits some smoking and some local increases in occupation density. Recent studies indicate that in many buildings most pollutants originate from the fabric, contents and the mechanical ventilation systems, and not the people. However, to improve conditions further, additional general ventilation has been shown to be much less effective than treating the problems at source: by specification, cleanliness and local extraction.

V2 *To provide natural cooling during the occupied period.* As a general rule, typical maximum natural ventilation rates in an office are in the range 4 to 8 ac/h. Above this, difficulties tend to occur with draughts, papers blowing about, and so on. Higher rates are practicable in temporarily-occupied spaces such as atria. A maximum of about 6 ac/h is usually the upper limit where mechanical ventilation is used for cooling: beyond this the fan energy consumption is such that some mechanical cooling will often be a more effective and lower-cost solution. To minimise fan power, low-speed operation should also be available outside the peak periods.

V3 *To provide natural cooling outside the normal occupied period:* in particular "night cooling" or "night purging". This can remove heat built-up in structure and contents and provide some pre-cooling for the following day. Its effect increases the more the air can "scour" the structure. Techniques range from exposed ceilings, through ventilated raised floors, to airways embedded in the structure: where these surfaces are not exposed to the room they may instead be used to pre-cool the air supply to the room during the day. With normal practical limitations upon secure openable area for natural systems and on duct size and fan energy consumption for ducted mechanical systems, practical night ventilation rates are often in the range 2 to 4 ac/h.

V4 *To exhaust heat and/or pollutants from localised sources or areas,* for example kitchens, toilets, vending areas and equipment rooms. This enables adjacent areas to be more comfortable with less conditioning. Exhaust air change rates are typically 5 ac/h or more in the spaces concerned. The systems often need to operate for longer hours that in the main spaces, and so independent extract systems are preferable. Good catchment of the air to be extracted is desirable, for example in closed rooms, with exhaust hoods, or with air extracted directly from the equipment concerned.

V5 *To act as a carrier medium for mechanical cooling and/or humidity control.* This can be either via all-air systems in which the air is treated centrally or via air/water or unitary systems in which the air is recirculated and treated locally. In either case, local air turnover rates in offices are often in the range 4 to 10 ac/h.

Table A3.1 outlines some technical methods of achieving each of these purposes, together with comments on strengths and weaknesses, and other comments. More information on energy-efficient ventilation is available in references [103] and [104].

TABLE A3.1		**PURPOSES AND METHODS OF VENTILATION: SOME STRENGTHS AND WEAKNESSES**		
	ITEM	***STRENGTHS***	***WEAKNESSES***	***COMMENTS***
V1	***BACKGROUND VENTILATION AND AIR QUALITY CONTROL***			
V1N	Natural trickle ventilation with local manual control.	Simple, low-cost, locally-adjustable. Uses no fan energy.	Somewhat haphazard. Unnecessary wintertime heat losses during unoccupied periods.	Heat recovery difficult. Most appropriate for shallow plan spaces. May sometimes need acoustic treatment.
V1A	Natural trickle ventilation with automatic control.	Relatively low-cost. Controllable as necessary.	Not widely used or understood.	Heat recovery difficult. Most appropriate for shallow plan spaces and open areas.
V1 M	Mechanical background ventilation.	Good control over quantity of air delivered. Tempering and heat recovery possible. Allows facade to be sealed and air conditioning etc. to be added if necessary.	Higher capital cost. Predicted energy cost savings from heat recovery often evaporate in practice once additional ventilation, electricity for fans and heat for air tempering and frost protection are taken into account.	May need zoning, particularly if used to support local air conditioning or heat removal, or if occupancy hours are diverse. Modular, locally/centrally-controlled ventilation units are possible (as at Inland Revenue Nottingham).
V2	***NATURAL COOLING DURING THE OCCUPIED PERIOD***			
V2N	Manually-operated windows	Obvious, understandable, readily adjustable. Different elements may be required for local and for cross-ventilation.	Can be problems with noise, dirt, draughts and security. Better for those sitting near than distant.	Useful safety-valve for discomfort-alleviation. However, occupants do not usually exercise control until they become uncomfortable, so some actions may be taken too
V2A	Mechanically-operated windows or ventilators	Automatic control possible in anticipation of need and for the general good. Manual remote control possible without going to a window. Less restrictive on furniture layouts. Less loss in area for window access?	Occupants at their workstations seem to dislike automatic control which perceptibly alters positions of windows (or blinds) in their territory or changes air movement patterns.	Automatic control possible, e.g. for night cooling. Occupants inboard may be given remote control of upper parts of windows. Experience with blinds suggests that if visible operation occurs during occupied hours, user over-rides will be essential.
V2 M	Mechanical ventilation	Helpful in deeper spaces, for internal rooms, on noisy or polluted facades, and to improve air movement.	Limited cooling effect. Care is required to minimise fan energy consumption, which may be high.	Relatively narrow window of opportunity, but in MM designs MV can usefully assist NV, for example in internal areas. Avoid unwanted air tempering when in cooling mode.
V3	***NATURAL COOLING OUTSIDE THE OCCUPIED PERIOD***			
V3N	Manually-operated windows	Simple, straightforward. Modular zoning. Windows opened in the day will tend to be left open overnight.	Possible problems with security, insects, rain or excessive cooling (particularly over weekends).	Hopper fanlights have worked well in several buildings with exposed ceilings, particularly where there are attentive security staff.
V3A	Mechanically-operated windows or ventilators	More precise and reliable operation possible than with manual control.	Additional capital and maintenance costs. Uncertain reliability.	Potentially useful if they can be afforded. Product development may be necessary.
V3 M	Mechanical ventilation	More controllable. Opportunity to increase effectiveness by passing air through voids in the structure.	Higher energy and operating costs. If not suitably zoned, areas with lower heat gains may be over-cooled.	Mechanical ventilation systems, if present, can serve multiple duties. However, zoning needs care.
V4	***LOCAL EXTRACTION OF HEAT AND POLLUTANTS***			
V4N	Via openable windows	Simple and straightforward, particularly in enclosed rooms.	Somewhat haphazard. May be difficult to leave open at night.	May sometimes be satisfactory for small, closed rooms. Danger of over-cooling.
V4P	Via passive stacks	Simple and straightforward.	Lacks locational flexibility.	Most suitable for fixed facilities such as WCs.
V4L	Via local mechanical extract	Local systems can be sized and controlled according to need.	Local units may not always be easy to accommodate or adapt.	Consider design strategies to permit modular units to be added (and removed) easily.
V4 M	Via central mechanical extract	Easier to plug in anywhere. Heat can be recovered easily.	May not be possible to recirculate the air. May be difficult to accommodate out-of-hours use economically.	Most appropriate when extraction only required during normal hours. Otherwise consider local extraction or possibly demand-activated VAV extract.
V5	***CARRIER MEDIUM FOR MECHANICAL COOLING AND/OR HUMIDITY CONTROL***			
V5	Background mechanical ventilation	Meets internal air quality requirements when windows are closed.	Can be wasteful if one uses large central systems to meet local extended-hours requirements.	Zone both ventilation and cooling carefully in order to avoid the energy waste that occurs when large systems are operated to meet small local demands.

A3.2.2VENTILATION AND AIR MOVEMENT

Ventilation is also associated with air movement. Typically velocities of between 0.1 and 0.15 metres/sec can help the atmosphere to feel “fresh”. Higher velocities can provide a useful cooling effect when it is warm, but can be a nuisance if they are perceived as a draught or if they blow things around. It can be difficult to please everybody, and for higher velocities ideally one should be able to choose “where to put the draught”. With natural ventilation, this option is usually only available to people who sit immediately beside windows: not only do they have control, but near the inlet or outlet the location of the draught is less affected by changes in wind direction and by window opening elsewhere. With mechanical ventilation or air-conditioning there is often no choice at all, and many complaints appear to originate from:

- obstructions, clashing airstreams, or loss of Coanda effect, causing air to “dump” locally (but this can also happen with natural ventilation [27]);
- unsuitable air velocities, particularly where furniture arrangements trap stagnant pockets or alternatively do not allow people to vary their seating positions in order to get out of the way of local draughts (or into local airstreams in hot weather);
- floor supply systems, where facilities managers have often had to relocate the outlets further away from desks and into the corridors (or occupants adjust the dampers or put waste paper bins over them);
- varying air distribution patterns with changing load: the control range of many VAV systems has needed to be altered to minimise such complaints.

MM systems are not immune from such problems, both from windows and mechanical systems: for example changeover operation may cause different local problems in each state. However, there may also be benefits: for example a small amount of window-opening in a pressurised building can provide some psychological relief, widening tolerance margins whilst creating little or no draught.

A3.3 Purposes and methods of mechanical cooling

A3.3.1MECHANICAL COOLING OPTIONS

The purposes of mechanical cooling are fewer than those of ventilation: it is to take out more unwanted heat (and sometimes moisture) than natural or mechanical ventilation can reasonably do. However, the available technologies are diverse. Table A3.2 provides an abbreviated list of mechanical cooling options thought to be of greatest applicability. It also gives comments on their general suitability for use in combination with natural and mechanical ventilation in MM systems. The more innovative possibilities are not included, not because they hold no interest or applicability, but because it is difficult to generalise about them.

A3.3.2 SUITABLE COMBINATIONS

While almost any combination of systems is possible, the most frequent choices tend to be central or zonal cooling via constant volume all-air systems, and local modular cooling via fan-coil units. There is also increasing interest in combining openable windows with displacement ventilation and/or ventilated structures, supplemented if necessary by chilled beams, though as yet there are few UK examples with operational experience.

TABLE A3.2		MECHANICAL COOLING OPTIONS		
	TECHNOLOGY	***STRENGTHS FOR MIXED MODE***	***WEAKNESSES FOR MM***	***COMMENTS***
C1	***ALL-AIR SYSTEMS***			
C1.1	Constant volume: minimum air supply, (typically 1 to 3 ac/h)	If background mechanical ventilation is present, cooling and dehumidification can easily be added to it to boost performance. Can combine with fabric storage.	Limited cooling capacity. Openable windows may clash and waste energy (but not necessarily very much).	Potentially low-cost boost for extreme weather, particularly if combined with floor supply or night cooling. Ground and top floors in particular may need zoning to reduce temperature offsets. 100% fresh air system practicable.
C1.2	Constant volume: typical air supply 4 to 10 ac/h	As above but giving higher cooling capacity.	Fan energy consumption can be high. Energy waste from clashes with window opening is more likely.	Possible for contingency or changeover mode, but normally there will be more appropriate options. Needs good zoning. For economy, consider two-speed or variable speed systems. Variable recirculation desirable for energy saving.
C1.3	Variable air volume	Can provide more demand-responsive boost. Could interlock local unit controls to window opening. Provides local control.	Potential clashes. Expensive unless used with discretion. More likely to cause draughts.	Probably most appropriate for contingency designs or for particular zones or tenancies.
C1.4	Displacement ventilation	Fairly simple air tempering and control requirements. Can also benefit from cooling of floorslab.	Turbulence from natural ventilation will tend to undermine the displacement effect.	Displacement effect tends not to be very good in offices anyway.
C2	***AIR-WATER SYSTEMS***			
C2.1	Fan coil units (FCUs)	May be used ad hoc for local comfort cooling. Do not necessarily need fresh air supply. Can be interlocked to windows. Good local control.	Condensate drainage (unless windows are shut and supply air is available and dehumidified).	Potentially useful both for local ad hoc cooling and for changeover operation. Relocatable FCUs with plug-in connections are possible. Possible problems with chilled water sizing and efficient operation to suit dispersed loads.
C2.2	Unit air-to-water heat pumps (e.g. Versatemp)	As FCUs, but do not require central chiller but merely heat rejection circuit. Heat recovery potential.	As FCUs. Heating mode probably unnecessary. Local control not as good as for chilled water.	As FCUs but possibly more suitable for demand-activated control and modular development. May be less or more economical depending on system use and design.
C2.3	Induction units	Most suited to concurrent or changeover. Good local control, particularly with VAV.	Probably relatively expensive. Not suited to ad hoc loads.	Reportedly used successfully in Germany. Probably limited application in the UK. Best for concurrent operation.
C3	***UNITARY SYSTEMS***			
C3.1	Through-the wall units.	Traditional ad hoc solution.	Messy, noisy. poor air distribution.	Not normally appropriate in the UK.
C3.2	Split units.	Useful ad hoc solution.	Where do you put the condensers? If the system is altered, refrigerant will tend to be lost.	Not normally ideal. Careful architectural thought is needed to control unit, condenser and pipework location. Adverse environmental impact of refrigerants.
C3.3	Multi-split units (viz VRV)	Useful zonal solution for supplementary comfort cooling.	High charge of refrigerant. Not as readily adaptable as FCUs after fitting. Refrigerant loss on alteration.	Potentially useful for zones with local permanent requirements, but not as adaptable as C2.1 or C2.2. Adverse environmental impact of refrigerants.
C4	***STATIC COOLING***			
C4.1	Embedded coils	Useful for lowering radiant temperatures.	Limited cooling capacity.	Needs to be done throughout at the beginning. Interesting for low-energy designs requiring some cooling.
C4.2	Chilled ceilings	Little maintenance required in the room. Potentially good local control.	Relatively expensive. Condensation risk if windows opened or supply air is not dehumidified. Any advantage of exposed soffits is lost.	Limited applicability.
C4.3	Chilled beams	As chilled ceilings, plus good for local ad hoc spot cooling.	Condensation risk if windows opened or supply air not dehumid-ified in humid summer weather.	Additional cooling capacity available with ventilated or powered chilled beams. Chiller/chilled water sizing problems as for FCUs.

A3.4 Provisional conclusions on MM strategies

A3.4.1 HOW MUCH FURTHER CAN ONE GO?

The above discussion can help to establish possible strategies for ventilation and cooling and the constituent components. However, to go much further in general terms becomes increasingly difficult as the number of permutations blossom. Further development is probably best undertaken in project-specific terms between between designers and their clients.

A3.4.2 A PRACTICAL APPROACH

Amongst the wide range of possibilities, some are of particular practical or topical interest at present. Part B - Mixed Mode in Practice - therefore attempts to identify the principal concerns of today and the opportunities for the near future, and to discuss issues which may be of particular importance to the achievement of robust, effective and efficient MM designs.

PART B **MIXED MODE IN PRACTICE**

B1 Introduction

B1.1 This part of the report outlines features of MM buildings (largely offices) that we are aware of either through direct experience (nearly half have been visited by team members), via colleagues or through the literature. It outlines some of their design features, relates them to the MFP classification, and identifies common characteristics. For the buildings visited, it also includes comments on changes made and problems encountered. This helps to identify some of the design and management issues to be discussed in Part C. All buildings included are either occupied or under construction: design studies and unbuilt designs are not included.

B1.2 All the buildings outlined are in the UK. A review of Continental European practice is also recommended: MM is common in some countries and we have already visited a few examples. However, design requirements and market conditions can be very different from those in the UK: for example with higher space standards, and often quasi-domestic situations with many individual perimeter rooms. Objective data is also highly elusive.

B2 Characteristics of existing designs

B2.1 MM BUILDINGS PREVIOUSLY VISITED BY WBA
On previous projects, WBA has visited 27 MM buildings, many of which have been surveyed in some detail. Some of their features are summarised in Table B1. The first page of this:

- Summarises the design intentions of their ventilation and cooling systems under the MFP classification.
- Notes the main air supply location: ceiling, floor, wall or natural (or “none” for contingency designs currently with natural ventilation only).
- Notes the predominant ceiling type: suspended, exposed, partial(ly suspended) and varies (some of each).
- Notes the heating system, mostly perimeter radiators or convectors.
- Identifies other key points.
- Notes changes to their design and operation which have occurred in use.
- Comments on these and other issues.
- Makes reference to any publications.

On the second page of Table B1, some key features are summarised.

B2.2 OTHER MM BUILDINGS IDENTIFIED
Table B2 lists other MM buildings identified, categorised as in Table B1, and with notes on some key features. Most of these are either under construction or have been completed within the past three years - on average they are eight years younger than those in Table B1. Most are owner-occupied or pre-let, three are speculative, and many of the others have also had to take some account of investor and property market requirements.

B2.3 CLASSIFICATION OF THE DESIGNS
Over three-quarters of the buildings visited and about half the newer designs were designed for *concurrent* operation. For the newer buildings, *concurrent* remains the most common operating strategy but *changeover* is more common. However, experience with the older buildings suggests that in practice *changeover* systems are not always controlled as the designers anticipated, see B4.3. Several buildings were *zoned*, with additional or independent servicing. A few had deliberate *contingency* strategies, including one from the 1970s with contingency to remove air-conditioning, and which may soon be activated.

	TABLE B1										MIXED-MODE BUILDINGS VISITED BY WBA: DESIGN INTENTIONS AND CHANGES DURING USE			
	Page 1		*Predominant modes are in bold type*											
	BUILDING		***DESIGN INTENTIONS:***								***NOTES***	***CHANGES IN USE***	***COMMENTS***	
	Numbers in the "Design Intentions" columns give the approximate air changes per hour of any mechanical ventilation systems >>>>>>>>>	***Approx date***	***Contingency***	***Concurrent***	***Changeover***	***Zoned***	***Air supply***	***Ceiling***	***Heating***	***HVAC classification***				***REFERENCE***
1	Akzo UK Headquarters and Training Centre, Milton Park, Oxon	1991	Cooling coils possible	**Yes MV 6**	More FA in summer	Yes	Floor	Susp'd	Via air	MV	Central air plus floor downblow fan coils. Pressurised.	Commissioning poor: re-done and BEMS added. Management requirement over occupant norms.	Ventilation plant too powerful. Intake air heated by hot roof, fan gain and heat exchanger.	81
2	Barclays Bank Regional Head Office refurbishment, Reading	1978	**Yes, to add fan-coil**	Added MV 2		Part AC	B'head	Exp'd	FCU	DAC	FCUs provided initially but without FA and chilled water.	Contingency AC added fairly soon after occupancy. Contingency air duct hi-jacked by a shop tenant!	One department had AC, then it snowballed. Noisy when planned street closure abandoned.	80
3	Body Shop HQ, Littlehampton	1991	**Yes, to add full A/C**			Local	None	Susp'd	Perim	Cont	Designed for full VAV AC to suit investors.	Mechanical cooling has been added in ground floor laboratories. Internal blinds added in offices.	Design of windows and lighting controls was improved by strong client involvement.	8 10
4	BRE Low-Energy Office, Garston (upgraded)	1980	Cooling coils possible	**Yes MV 3.6**	Poten-tially		Wall	Varies	Perim	BV/MV	Fabric & energy figures with new windows and cond boilers.	Winter HR ventilation was intended to save primary energy but used more. Blind maintenance problems.	Mechanical night cooling was disappointing, and used too much energy at high speed.	59
5	British Aerospace Space Systems, Stevenage	1988	Cooling coils possible	**Yes MV 10/15**			Column	Susp'd	Perim	MV	Double gallery, central return air atrium.	AHUs had to run constantly in summer to keep plants in glazed atrium return air route alive.	High change rate, pressure & run time gave very high fan energy. Atrium needs separate ventilation.	81
6	Civic Offices, Salford	1973	**Yes to remove AC**	**AC 2**	C/O induct'n AC	Local	Ceiling	Susp'd	Incuct	DAC	Shallow plan A/C office. Contingency provision to revert to NV.	Following complaints, the windows were unlocked to give ad hoc MM operation.	Complaints partially because of mid-season problems with change-over induction AC.	60 83
7	Computer Science D-block, York University	1985	Partly		**Night Cool**	Yes	Nat	Exp'd	Perim	MNV	Teaching labs only have coffered slabs and mech night extract vent.	Security stops added to ground floor sash windows (small H/L night vent louvres OK).	Secure natural supply/mechanical extract (manual on/auto off). Very efficient use of energy.	84 Site.
8	Courage Head Office, Ashby House, Staines	1990		**Yes AC 3**	Chilled ceilings if hot	Local AC + FCUs	C'ling	Susp'd	Perim?	DAC	T&T windows. Ext Auto V blinds (wind damage problems)	Window opening in sultry weather gives condensation on chilled ceilings. AIR conrtrols removed.	High energy use. Constant chilled water to (small) equipment rooms. Blind/light control not coord.	83
9	Guardian Newspapers, Farringdon Road	1975		**Yes. MV 2**			B'head	Susp'd	Ht pump	DAC	Upgrade of NV space with min fresh air and perimeter heat pumps.	Some unified control of ht pumps to reduce offsets. NV louvres closed.	Relatively poor air distribution. Notchy control of heat pumps gives patchy temperatures.	80
10	Hereford and Worcester County Hall	1977	Can add chiller battery	**Mainly MV 5**	Planned at peri-meter	Cooling in some zones	C'ling	Susp'd	Perim	MV+SC	Design requirement for building to be usable in a power cut.	Separate winter, summer and mid-season operation proved too complicated.	Concurrent operation adopted with winter heating/summer cooling.	19
11	Inland Revenue, Nottingham.	1994		**Yes local MV**	**Night cool**		Cill/flr	Exp'd	Trench	BV	Captive venetian blinds adjustable for angle only (fixed in top lights).	Stack ventilation towers needed netting to stop pigeons roosting. Lightweight top floor hotter.	Occupants choose under-floor fan speed. Fans automated for night cooling. Top floor rooflight vents.	50
12	Lloyds Insurance, Chatham	1978	Some	**Mainly MV 4**		AC in deeper spaces	C'ling	Susp'd	Perim	MV	Echelon facade with variable depth. Pyramid ceilings.	Not known. Draughts and rain come through horizontal slider windows on exposed site.	Cooling is only available in the deeper spaces: some adverse comparisons in hot weather.	82
13	Mendip District Council Offices, Shepton Mallet	1987	Cooling coils possible	**Yes MV 4**		Some	Wall	Varies	Perim	MV		Not known	Mechanical ventilation to core only to permit 18m office depth and some internal rooms.	80
14	NFU Mutual & Avon Group HQ, Stratford-upon-Avon	1983	Can add chiller battery	**Mainly MV 2/4**	Night cooling	Yes: part A/C.	C'ling	Exp'd	Perim	BV/MV	Simplified operating strategy after No 10. S/ pool data not included.	4 ac/h not used: unnecessary and rather noisy. Mechanical night cooling was also not required.	Hoppers left open gave sufficient night cooling. Security closes if cold. Some motorised ext VBs.	8 58 81
15	Policy Studies Institute, London NW1	1986				**Yes, part MV 6**	C'ling	Varies	Perim	MV	Research institute with many small cellular offices.	None	Mechanical ventilation in atrium and surrounding offices (not popular) and meeting rooms only.	18
16	Posford House, Peterborough	1990		**Yes MV2/6**	Higher summer ac/h		Floor	Susp'd	Elec	BV/MV	All-elec. Floor supply ducted to each bay. Cool air intake at NE cnr.	Night cooling seldom necessary. Early-morning start-up is usually enough in hot weather.	Air change could be too high for gain levels. Night cooling needs zoning by floor to stop offsets.	8 61
17	Provincial Insurance, Kendal	Various	Cooling coils possible	**Partly MV 6**		**Yes**	Cill	Susp'd	Induct	MV	Visited but rejected for BRECSU/EEO case study.	Heat recovery added from computer suite to induction AHU in 1970s major extension.	Windows little used: secondary glazing inhibits operation. Heat recovery: high parasitic losses.	80
18	Refuge House, Wilmslow	1987		Some	**Yes AC 1.2**	Local	Cill+flr	Exp'd	FCU	DAC	Courtyard/ladder plan explicity designed for unpredictable IT gains.	Concurrent operation now adopted for convenience. Plant well managed. BRECSU case study.	Energy consumption reasonable. Many hidden control obstacles found to using night ventilation.	20 70
19	Research Machines, Milton Park, Oxon	1991	**Yes**		Hot void extract	No	None	Susp'd	Perim	Cont	Small office around court on front of factory unit.	Comfort cooling has been added owing to increased occupancy and internal gains, plus partitioning.	Major organisational changes occurred since the building was commissioned.	81
20	RMC Headquarters, Staines	1989		**Yes MV 6**	Night cooling	Local	Floor	Varies	Trench	MV	Largely single-storey. Garden on roof.	Monitoring showed attention was required to dampers, controls and heat letting by in night vent mode.	Needed better night ventilation control and better thermal contact between supply air and floorslab.	8 106
21	Scottish Office, Victoria Quays, Leith, Edinburgh	1995	Some	**Yes MV 2/4.5**	Mech Night Vent.	Dining Mtg. Eqpt.	Floor	Partial	Perim	BV/MV	Ladder plan with central courts and atria.	Local lighting controls to be added (were budgeted but not included in fitout for some reason).	Changeover option to switch MV off in mid-season. High initial energy use being investigated.	30
22	Solid State Logic, Begbroke, Oxon	1988	Some	**Yes MV 6**			Floor	Varies	Trench	MV	Floor supply upstairs, ceiling downstairs. Central atrium.	Extra lights and switches added. Solar film added. Poor reliability of auto external Venetian blinds.	Site specific design, surrounded by trees. Users didn't like blinds up/down only.	62
23	South Glamorgan County Hall, Cardiff	1988	Some	**Yes MV 4-6**		Local	C'ling	Susp'd	Perim	MV	AC removed from scheme after occupant survey.	Can be hot in summer owing to low thermal mass with suspended ceilings and intake over hot roofs.	Not BRECSU case study owing to peak temps. Design not altered enough after AC removed?	80
24	S Northamtonshire District Council, Towcester	1982		**Yes. MV2?**		Centre +Cncl Chmbr	Perim	Susp's	B'head	DAC	Partial changeover system with HR chiller, FCUs + ht pumps.	"Window opening frowned upon". Some windows have been locked-off.	All-electric. EMEB design. Visited but rejected as possibility for BRECSU case study.	80
25	Tanfield House, Edinburgh	1990		**Yes VAV 8 max**		Local	Floor	Exp'd	Perim	CAC	Upper sashes auto controlled for smoke vent. Sprinklered.	Increased running hours to suit late working and health comments.	Openable windows (onto a buffer space) mostly regarded as a nuisance in this very deep space.	21
26	Weidemuller, Kings Hill Business Park, Kent	1993		**Yes MV 2 const**	Summer a'batic cooling	Extra local extract	Wall	Exp'd	Elec	TC	Termodeck ventilated hollow floor planks. Regenerative HR.	Indirect evaporative cooling (via heat exchanger in exhaust duct) not very effective in summer 1994.	Specific fan power far too high at 3 W/l.s . Air intake over hot roof. Duct leakage. Unwanted Ht Rec.	80 92
27	Constable Terrace student housing, UEA Norwich	1994		**Yes MV 1**			L/I wall	Exp'd	Elec	TC	Domestic-style MVHR scheme with windows & elec heaters.	Intakes modified to stop cooking smells being recirc to rooms via mechanical system.	Smells led to energy loss by extra window-opening. Zoning+heat recovery problem in vacation.	57 93

TABLE B1
Page 2
BUILDING

No.	Building	*Procurement*	*Main form (see figure B1)*	*Nett area*	*Main orientation*	*Glass-glass depth (m)*	*Facade module (m)*	*Ceiling height*	*Proportion cellular*	*Wall construction*	*Wall U*	*Roof type*	*Roof U*	*Main walls glazed*	*Glazing % of main walls*	*Glazing type*
1	Akzo UK Headquarters and Training Centre, Milton Park, Oxon	Prelet	ELL	2400	N-S	14.4	3.6	2.6	10%	Brick	0.6?	Pitched	0.45?	N-S	30%	Dbl tint
2	Barclays Bank Regional Head Office refurbishment, Reading	O-occ	CRT	2500?	All	Varies	Varies	Varies	40%?	Brick/PC	0.6?	Varies	Varies	All	30%	Varies
3	Body Shop HQ, Littlehampton	Prelet	CRT	5000	NSEW	12.0	1.2?	2.7	Small	Brick	0.4?	Pitched	0.3?	All	50%	3ple
4	BRE Low-Energy Office, Garston (upgraded)	Public	LIN	1400	N-S	12?	3.6?	2.6?	80%	Precast	0.45	Invt'd	0.3	N/S	30/45%	DbleE
5	British Aerospace Space Systems, Stevenage	O-occ	STR	7000	E-W	12.0	1.2?	2.6	20%	Brick	0.6?	Invt'd	0.5?	All	30%	Dbl tnt
6	Civic Offices, Salford	Public	LIN	5900	NE-SW	12.0	1.5	2.7	20%?	Precast	0.6?	Flat	1.0?	2	25%	Twin
7	Computer Science D-block, York University	Public	LIN	1200	E-W	18.0	3.6	2.7	35%	Brick	0.6?	Pitched	0.4?	2	35%	Most dbl
8	Courage Head Office, Ashby House, Staines	O-occ	CRT	6900	N-S?	12to18	3.0?	2.6?	20%?	Brick	0.6	Pitched	0.5	All	0.7?	Dble E
9	Guardian Newspapers, Farringdon Road	O-occ	LIN													
10	Hereford and Worcester County Hall	Public	Pavilion	18000	All	25.0	3.7	2.7+	15%	Brick	0.6	Pitched	0.6	All	60%	Most dbl
11	Inland Revenue, Nottingham.	Public	CRT		All	13.6	3.6	3.2	20%	Precast	1.5?	Pitched	0.3?	All	80%	Double
12	Lloyds Insurance, Chatham	O-occ	BLK	10000	All	Varies	2.4?	2.7?	20%?	Brick?	0.8?	Pitched	0.6?	All	60%	Sngle
13	Mendip District Council Offices, Shepton Mallet	Govt	LIN			18m	2.4	2.7	25%?	Brick	0.4?	Pitched	0.4?	All	40%	Double
14	NFU Mutual & Avon Group HQ, Stratford-upon-Avon	O-occ	LAD	9870	NW-SE	18m	3.6	3.3	20%	Stone	0.4	Invt'd	0.3	NW-SE	30%	Dble+Tw
15	Policy Studies Institute, London NW1	Prelet	Triangle		All	Varies	2.4	2.4	60%	Brick	1.2?	Flat	0.6?	All	25%	Dble
16	Posford House, Peterborough	O-occ	LIN	1150	N-S	15.5	3.0	2.7	5%	Brick	0.3	Pitched	0.3	N-S	20%	L.tint/Ar
17	Provincial Insurance, Kendal	O-occ	BLK	Reverted to mechanically-ventilated. Not much further detailed interest.												
18	Refuge House, Wilmslow	O-Occ	LAD	9900	NW-SE	12/15.	3?	3.0	15%?	Brick	0.6	Pitched	0.4	All	30%	Twin
19	Research Machines, Milton Park, Oxon	Prelet	CRT	800	N-S	8.0	1.5	2.6	20%	Brick	0.4?	M'ptch	0.4?	N-S	40%	Dble
20	RMC Headquarters, Staines	O-occ	FIN	4500	NS	18.0	3.6?	2.9	60%	Patio Dr	3.6?	Invt'd	0.3?	2	75%	Dble
21	Scottish Office, Victoria Quays, Leith, Edinburgh	Prelet	LAA	27600	N-S	15/10.5	1.5	2.9	10?	Precast	0.28	Invert	0.21	2	50%	1+2
22	Solid State Logic, Begbroke, Oxon	O-occ	BLK	3000	NSEW	42.0	3.6?	2.7?	10%?	Glass	3.3?	Flat	0.2	All	100%	Dble
23	South Glamorgan County Hall, Cardiff	Public	CRT	18500	All	Typ 15	1.5	Varies	75%?	Brk+CW	0.6?	Pitch	0.4?	All	30%	Dble
24	S Northamtonshire District Council, Towcester	Public	Cross	3100	All	11	1.35	2.6?	Most	Brick	0.45	Flat?	0.25?	2	30%?	Dbl Tint
25	Tanfield House, Edinburgh	O-occ	ATR x3	20000	All	V deep	NA	3.6	5%	Curtain	1.5?	Invtd	0.4?	All	70%	2+1 Tint
26	Weidemuller, Kings Hill Business Park, Kent	Prelet	BLK	1500?	All	30m?	3.0?	3.0	?	Brick	0.2	Pitch	0.2	All	20%?	2+1
27	Constable Terrace student housing, UEA Norwich	Public	LIN	5000?	All	NA	NA	2.4	All	Block	0.22	M'pitch	0.15	2	15%	Dble E

No.	Building	*Frame type*	*Window U-value*	*Upper window*	*Middle Window*	*Lower window*	*Pri. solar protection*	*Sec. solar protection*	*Cross-vent*	*Other exhaust route*	*Lighting*	*Illuminance (lux)*	*Control*	*Occupancy m2/p des:actual*	*W/m2:* *Lighting gains inst:summer*	*Equipment gains des:act*	*Fan power high:low speed*
1	Akzo UK Headquarters and Training Centre, Milton Park, Oxon	Al	3.2?	T/hung	T/hung	No	S o'hang	Tint	Some	Ceiling	Rec F	450	Grid	?/20	16/16	?/12	?
2	Barclays Bank Regional Head Office refurbishment, Reading	Varies	Ave 4?	U/sash	L/sash	None	Street	Int VB	Some	B'head	Surf F	200/600	3 steps	?	20/15?	?	2?
3	Body Shop HQ, Littlehampton	Al/tim	1.8?	None	Revers	None	O'hang	Pleatex	Good	No	Rec HF	≤500	Lo dim	10:09	12:04	15:12	None
4	BRE Low-Energy Office, Garston (upgraded)	Al	2.2	Non	C-pivot	None	Awning	Varies	Seldom	B'head	Surf fluo	350	Local	12?	14/4.	NA	NA
5	British Aerospace Space Systems, Stevenage	Al	3.6	U/sash	L/sash	None	Timt	Int VVB	Poor	C'ling	HID up	470	Grid	?/12	22/22	?/21	20?
6	Civic Offices, Salford	Timber	2.4	No	C/pivot	No	Recess	Mid V	Yes	Ceiling	Rec F	500	Pull cord	15:?	25:10	3:10	
7	Computer Science D-block, York University	Timber	3	Louvre	U/sash	L/sash	Trees	Internal	No	Ceiling	Surf F	350	Door		25:10	NA	
8	Courage Head Office, Ashby House, Staines	Al	2.8	None	Fixed +	T&T	O'hang	Ex MVB	Some	Ceiling	Rec F	450	Timed	?:20	15:14	?:28?	
9	Guardian Newspapers, Farringdon Road			Louvres	C-pivot	None											
10	Hereford and Worcester County Hall	Al	3.8	Fanlight	Fixed	NA	S'breake	None	Some	Ceiling	Rec F	600	Auto	11/?	16:10	NA	?
11	Inland Revenue, Nottingham.	Al		Fixed	Patio dr	N/A	Mid-V	None	Yes	Stair	Rec HF	Variable	AIR/time		12:08		
12	Lloyds Insurance, Chatham	Al	6	Trickle	Slider	N/A	O'hang	Curtains	Some	Ceiling	Rec F	500	Grid		22:22		
13	Mendip District Council Offices, Shepton Mallet	Timber	2.8	Louvre	U/sash	L/sash	None	Blinds	Yes	Clerestry	Rec F	350	Grid	?	15:12	?	?
14	NFU Mutual & Avon Group HQ, Stratford-upon-Avon	Teak+Al	2.8	Hopper	C/pivot	NA	S'break	Mid V	Yes	B'head	Susp F	350	Auto/ma	11:09	14:07	3:15	2/0.5
15	Policy Studies Institute, London NW1	Al	3.3	None	C/pivot	None	None	Curtains	No	Atrium	Rec F	600	Door	Varies	22:05	NA:5	NA
16	Posford House, Peterborough	Timber	1.6	None	T&T	None	Wall	Roller	Yes	Ceiling	Rec HF	550	Man/aut	?/18	15.5:11	?/5	3/0.6
17	Provincial Insurance, Kendal																
18	Refuge House, Wilmslow	Al	3.3	None	T&T	None	Mid-V	No	Yes	Floor	MBI up	400	Man/aut	10:10	19:18	Var:14	1.2
19	Research Machines, Milton Park, Oxon	Al	3.6?	T/hung	T/hung	Some Fi	S'brkr	Int VB	Yes	C void	Rec F	420	Local	?	11:?	?	NA
20	RMC Headquarters, Staines	Al	3.6?	None	Patio Dr	Csemnt	O/hang	Int V	Some	B'head	Fluo	500	Local	25:25	21:18	NA	NA
21	Scottish Office, Victoria Quays, Leith, Edinburgh	Al	1.9	Hopper	C/pivot	Fixed	Mid V	None	Yes	Ceiling	Rec HF	500	Auto/tel	15:?	10:9?	21:?	10:02
22	Solid State Logic, Begbroke, Oxon	Al	3.3?	Non	Patio dr	None	O'hang	Ext VBs	Yes	Ducted	CFL	?	Manual	?	25?	?	8?
23	South Glamorgan County Hall, Cardiff	Al	3.3	None	Hopper	Some	O'hang	Intl	Some	Ducted	F+SON	500	Reset	15:15?	12:10	NA	5?
24	S Northamtonshire District Council, Towcester	Al	3	None	C/pivot?	None	Tint	Intnl	Cellular	Ducted	Rec F	750?	Manual	Vary:10	36!	?	?
25	Tanfield House, Edinburgh	Al	2.0?	U/sash	L/sash	None	O'hang	2 layers	No	Atria	HID up	350	Auto	14:14	13:13	45:15	Ave 18
26	Weidemuller, Kings Hill Business Park, Kent	Al?	1.9	None	T&T?	None	Wall	Mid V	Little	B'head	S/fluo	?	Tenant	?	?	?	3W/ls
27	Constable Terrace student housing, UEA Norwich	Al/wood	1.8	None	T-hung	None	None	Curtain	None	via bath	NA	NA	Local	NA	NA	NA	?

No.	Building	*Energy use/yr kWh/m2 TA* *Heating gas*	*Heating electricity*	*HWS gas*	*HWS elec*	*Humidification*	*Cooling*	*Fans & pumps*	*Lights*	*Office equipment*	*Other*	*Catering gas*	*Catering electricity*	*Computer/Comms room*
1	Akzo UK Headquarters and Training Centre, Milton Park, Oxon	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2	Barclays Bank Regional Head Office refurbishment, Reading	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3	Body Shop HQ, Littlehampton	NA	NA	NA	NA	NA	NA	NA	16 est	NA	NA	NA	NA	NA
4	BRE Low-Energy Office, Garston (upgraded)	65			5	None	None	2	12	6	10	None	Incl	None
5	British Aerospace Space Systems, Stevenage	NA	NA	NA	NA	NA	NA	NA	120 est!	NA	NA	NA	NA	NA
6	Civic Offices, Salford													
7	Computer Science D-block, York University											None		
8	Courage Head Office, Ashby House, Staines	261	None	15	None	?	118	65	57	49	39	15	15	incl
9	Guardian Newspapers, Farringdon Road													
10	Hereford and Worcester County Hall	90		8		NA	10	13	44	5	9.5	2.5	2	20
11	Inland Revenue, Nottingham.													
12	Lloyds Insurance, Chatham	98	None	10	None	None?	13	8	79	18	3		11	227
13	Mendip District Council Offices, Shepton Mallet	81	None	12	None	None	None	8	27	17	1		7	192
14	NFU Mutual & Avon Group HQ, Stratford-upon-Avon	103	No	11	1	None	2	8	20	9	6	18	9.5	98
15	Policy Studies Institute, London NW1	164	No	No	2	None	None	8	16	2	1.5	None	Incl	None
16	Posford House, Peterborough	No	61	No	3	None	None	18	30	13	1	None	2	No
17	Provincial Insurance, Kendal	94	No	No	2.5	None	3	26	74	20	5	None	5	339
18	Refuge House, Wilmslow	75		14.5		None	8	22	39	8.5	7	10	12	80
19	Research Machines, Milton Park, Oxon	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
20	RMC Headquarters, Staines	114.2	NA	Incl	NA	Na		17.2	47.3	13.5	4.2	Excl	Excl	Excl
21	Scottish Office, Victoria Quays, Leith, Edinburgh	107 est			3 est	None	9 est	9 est	26 est	26 est	Lift 5	NA	NA	NA
22	Solid State Logic, Begbroke, Oxon	62			8	None	None	39	78	7	72			
23	South Glamorgan County Hall, Cardiff	70	2	5	1	7	4	24	37	10	10	13	14	52
24	S Northamtonshire District Council, Towcester							*Total*	*all-*	*elec.*	*125*			
25	Tanfield House, Edinburgh	231		Incl	5	G 91	23	101	73	45	75			
26	Weidemuller, Kings Hill Business Park, Kent	None	38 mon	None	?	?	78 mon	?	?	?	?	None	?	NA
27	Constable Terrace student housing, UEA Norwich	None	33	70	12	None	None	18	19	>>	22	None	Incl	None

TABLE B2
Page 1 of 2

OUTLINE OF MIXED-MODE BUILDINGS REVIEWED IN THE TECHNICAL PRESS

Predominant modes are in bold type

Numbers in the "Design Intentions" columns give the approximate air changes per hour of any mechanical ventilation systems. >>>>>>>>>>>

	BUILDING	***DESIGN INTENTIONS:*** *Approx date*	*Contingency*	*Concurrent*	*Changeover*	*Zoned*	*Air supply*	*Ceiling*	*Heating*	*HVAC classification*	***NOTES***	*REFERENCES*
1	3 The Square, Stockley Park	1996	See notes.	When hot.	**Cold 3 Med NV Hot 6.**	If needed.	Floor	Exp'd	Perim	WW	Manually-controlled double-glazed sash windows onto corner conservatories, with blinds on censervatory side. Contingency: MV can be cooled; ceilings (market requirement) can be removed. Solar protected by conservatory roofs.	42
2	Addison Wesley Longman, Harlow	1996			**MV in winter ? ac/h**	Meeting K/dining A/C.	Floor	Exposed	Perim	MV	Just completed. Visiting 18 June. Top windows (above sunbreakers) etched.	91
3	Avon & Somerset Constabulary, Portishead	1995		**Yes. MV ? ac/h**		Local chilled beams.	Floor	Exp'd	Perim	?	Vaying form with cross-ventilated, courtyard and central atrium arrangements. No detailed information available.	38
4	Barclaycard, Northampton	1996		**Yes. MV 3?**	Chilled beams if hot.	AC in hi IT areas W side.	Floor	Exp'd	Perim	DAC	9 m central street. Floor supply. Chilled beams, lake cooling. High and low level windows. Not yet occupied.	49
5	British Gas, No 1 Leeds City Office Park.	1995	U'floor fan coils.	**MV 2.2**	**See notes**	Air locally tunable.	Floor	Partial	Perim	WW	Central atrium between two office "fingers". H/L and L/L windows + triclke vents. Additional night MV system 5 ac/h+atrium windows. Summer daytime MV only once building is warm. Can add shunt ducts over cellular offices.	34 86
6	British Gas, Loughborough Science Park	1993		**Yes. MV ? ac/h**			Floor	Exp'd	Perim	MV	15 m deep linked blocks with courtyard. More information being sought from British Gas.	51
7	British Gas, Thames Valley Park, Reading	1996	Cooling supply air.	**Yes. MV 3.**	Night cool pri NV	Special areas	Floor	Exp'd	Perim	WW	Finger plan with some linking atria. Top hung windows, posibly motorised. Cooling available on main air supply. Was pre-let to British Gas, but now spec owing to organisational changes.	
8	BSI, Chiswick	1994			**Inter-lock.**		Perimete	Susp'd	FCUs	DAC	Overclad refurbishment of tower block including fanlights with external weather louvres. Microswitch on fanlight cuts off under-cill fan-coil unit.	54
9	Charities Aid Foundation, West Malling	1995	Chilled beams planned	**Yes. MV 3.**	MV for night cooling.		Floor	Exp'd	Perim	BV	Upgrade options of chilled beam, FCU and VAV considered [31]. Chilled beam most economical. Lightshelves abandoned.	31
10	Defence Procurement Headquarters, Bristol	1996		**Yes. MV ? ac/h**			Floor	Exp'd	Perim	MV	Mixture of cross-ventilated and double galleries with central atria. No detailed information available, but could be obtained from Hoare Lea.	37
11	DTI refurbishment, Westminster	1995		**Usu-ally**	**In steps**	Special areas	Floor	Susp'd	Prim	WW+SC	Sec glazing with vented man/auto inter-pane blinds. Trickle vent (0.2-0.5 ac/h) + stack exhaust (0.4-0.8 ac/h) + floor supply (0.5-1 ac/h) with VS fans (0.8 - 3 ac/h). CO2 control. Chilled ceilings (dehum to 55% when on). Night cooling.	43
12	Elizabeth Fry Building, University of East Anglia	1995		**Yes. MV 4 max**			Ceiling	Exp'd	Via air	TC	Termodeck hollow core slabs. 3-speed AHUs. 24 hr ventilation. Reversing flow regenerative heat exchanger. Triple glazed low-E. No perim .heating. Includes lecture and seminar rooms. Airtightness 0.97 ac/h at 50 Pa.	56 69
13	Equity and Law, 175 Corporation Street, Coventry	1990		**Yes**			Perim?	Susp'd	Ht pump	DAC	Tilt-in (and turn?) windows over perimeter reverse cycle heat pumps. No detailed information available. Reviewed as a possibility for BRECSU case study but not visited.	
14	Gateshead Civic Offices	1988				**See notes**		Susp'd	Perim	NV+Z	Cross-ventilated courtyard plan. Local AC in council chamber, committee rooms, restaurant, equipment and Word Processing rooms. MV in atrium, basement and central cores.	39
15	IBM Software laboratory, Hursley Park, Portsmouth	1992			**Inter-lock.**		Ceiling	Susp'd	FCU	DAC	ATM modular fan-coil units interlocked with windows. Offices mostly cellular, but with high IT levels. "Combi" depth with some internal rooms. No detailed information available, but could be obtained from Procord.	40 44

	BUILDING	*Procurement*	*Main form (see figure B1)*	*Nett area (m2)*	*Main orientation*	*Glass-glass depth (m)*	*Facade module (m)*	*Ceiling height (m)*	*% cellular*	*Wall construction*	*Wall U-value (W/m2K)*	*Roof type*	*Roof U-value (W/m2K)*	*Main glazed walls*	*Glazing % of main walls*	*Glazing Type*	*Frame type*	*Window U-value (W/m2K)*
1	3 The Square, Stockley Park	Spec	Cross	6000?	All	18m	1.35?	2.8?	?	Curtain	?	Shallow	?	All	45%	Dble	Timber?	Wood?
2	Addison Wesley Longman, Harlow	O-occ	LAA	16000	E-W	13.5 m	1.5?	3m?	15%	Frme+cl	0.5??	Flat	0.3?	NSEW?	35%?	Dble	Al	3.5?
3	Avon & Somerset Constabulary, Portishead	Public	BLK+LIN		All												Al	
4	Barclaycard, Northampton	O-occ	STR	30000	N-S	15m	3.6?	3.3?	NA	?	?	Flat	?	N+S	45%?			
5	British Gas, No 1 Leeds City Office Park.	Spec	FIN	5200	All	15m	1.5	3.2	?	Curtain	0.23	Flat	0.26	All	42%	Dble E	Al?	2.8
6	British Gas, Loughborough Science Park	Spec	CRT	2850	All	15m	1.5m	2.975	?	Brick	0.25?	Barrel	0.3?	All	18%?	Dble	Timber	2.8?
7	British Gas, Thames Valley Park, Reading	Spec	FIN	6000	E-W	16.5m	1.5 m	1.5 m	?	Curtain	1.5?	Flat	?	All	70%	Hi perf	Al	1.5?
8	BSI, Chiswick	O-occ	L-TWR		All	15m?	1.8m?	2.6m?	10%?	Curtain	NA	Flat	NA	All	All	Dbl refl	Al	2.2?
9	Charities Aid Foundation, West Malling	Prelet	FIN(U)	3250	All	13.5m	3	2.9	Small	Brick	0.32	Inverted'	0.19	All	All	Dble E	Al	1.8
10	Defence Procurement Headquarters, Bristol	O-occ	LIN+GAI	120000	All													
11	DTI refurbishment, Westminster	Public	BLK	45000	N-S	18	1.5	2.6?	?	RC/stone	0.6	Inverted	0.45	All	50%?	2+1.	Timber	1.65
12	Elizabeth Fry Building, University of East Anglia	Public	LIN	3250	N-S	15m?	2.475	2.9?	Most	Block	0.2	Shade	0.15	2	2	2+1E	Al/tim	1.3
13	Equity and Law, 175 Corporation Street, Coventry	Prelet?	TWR		All	12?	1.5?									Refl E Al		1.5?
14	Gateshead Civic Offices	Govt	CRT	24900	All	15?	1.5?	2.4?	?	Brick	0.52	Pitched	0.24	All	35%?	Twin	Timber	2.7
15	IBM Software laboratory, Hursley Park, Portsmouth	O-occ	BLK															

	BUILDING	*Upper window*	*Middle Window*	*Lower window*	*Pri solar protection*	*Sec solar protection*	*Cross-vent*	*Other exhaust route*	*Lighting*	*Illuminance*	*Control*	*Occ m2/p des:actual*	***W/m2*** *Light gains inst:summer*	*Eqpt gains des:act*	*Fan pwr hi:lo speed*
1	3 The Square, Stockley Park	U/sash	L/sash	NA	O'hang	Ext	Yes	Mech ex	Fitout	300					
2	Addison Wesley Longman, Harlow	Hopper	T/hung	Fixed	S'bkr	Int roller	Some	Atrium	Fluo up	350	Auto				
3	Avon & Somerset Constabulary, Portishead	Some	T&T	Some	S/bkr	Int roller			Varies						
4	Barclaycard, Northampton	T-hung	C-pivot	NA?			Yes	Atrium							
5	British Gas, No 1 Leeds City Office Park.	Auto	T&T	NA	Walkwy	Tenant	Some	Atrium	HF fluo	400	PIR/AIR	13:?	12.5:?	15:?	2/3.
6	British Gas, Loughborough Science Park	U/sash	L/sash	No	Mass	Tenant	Yes	Mech	?	?	No	?	?	?	?
7	British Gas, Thames Valley Park, Reading	T-hung	Fixed	T-hung	Glass	Int?	Yes	Mech	?	350?	?	?	?	?	?
8	BSI, Chiswick	Hopper	Fixed	None			Some	Ceiling	Rec HF	?	?	?	?	?	?
9	Charities Aid Foundation, West Malling	Hopper	Pivot?	No	S'brkr	?	Yes	NA	HF CFL	400	Phone	20:20	13:?	15:?	12.5/?
10	Defence Procurement Headquarters, Bristol														
11	DTI refurbishment, Westminster	None	C-pivot	Fixed	Mid-V	No	No	Ceiling	SuspHF'	350	?	9:?	12:?	15-25:?	NA
12	Elizabeth Fry Building, University of East Anglia	None	Casemt	None	Mass	No?	No	B'head	Pelmet	350	Aut+loc	NA	12:10	2/?/?	NA
13	Equity and Law, 175 Corporation Street, Coventry	Fixed?	T&T?												
14	Gateshead Civic Offices	None	C-pivot	None	O'hang	Mid-V	Yes	Inernal	Rec Flu	250-750	Pullcord	20?	NA	NA	NA
15	IBM Software laboratory, Hursley Park, Portsmouth														

	BUILDING	***Annual energy use: kWh/m2*** *Heating*	*HWS*	*Humidification*	*Cooling*	*Fans & pumps*	*Lights*	*Small power*	*Other*	*Catering*	*Computer room*
1	3 The Square, Stockley Park					Fan 9 es					
2	Addison Wesley Longman, Harlow										
3	Avon & Somerset Constabulary, Portishead										
4	Barclaycard, Northampton										
5	British Gas, No 1 Leeds City Office Park.	G45	Incl	NA	NA	16	11	30	Lift 18!		
6	British Gas, Loughborough Science Park										
7	British Gas, Thames Valley Park, Reading	?	?	?	?	?	?	?	?	?	?
8	BSI, Chiswick	?	?	?	?	?	?	?	?	?	?
9	Charities Aid Foundation, West Malling	G 100	G 18	NA	NA	30	45	25	?		
10	Defence Procurement Headquarters, Bristol										
11	DTI refurbishment, Westminster										
12	Elizabeth Fry Building, University of East Anglia	26Est	Incl	NA	NA	Incl	16	8	*Hearsay*	*Totals*	*40G,52E*
13	Equity and Law, 175 Corporation Street, Coventry	121	Incl	None?			Total	BS elec	120 est		147 est
14	Gateshead Civic Offices	G 61	G7,E0.6	None	7	12.5	32.5	7.3	8.4	38.1	60
15	IBM Software laboratory, Hursley Park, Portsmouth										

TABLE B2 — **OUTLINE OF MIXED-MODE BUILDINGS REVIEWED IN THE TECHNICAL PRESS**

Page 2 of 2

Predominant modes are in bold type

Numbers in the "Design Intentions" columns give the approximate air changes per hour of any mechanical ventilation systems. >>>>>>>>>>>

#	*BUILDING*	*DESIGN INTENTIONS:* Approx date	Contingency	Concurrent	Changeover	Zoned	Air supply	Ceiling	Heating	HVAC classification	*NOTES*	REFERENCES
16	Inland Revenue, Durrington Bridge House, West Sussex	1995			**MV 1.5/4 ac/h**				Perim	BV?	Automatic hopper windows with manual windows underneath. Atrium wall is solid, with window openings. Night cooling as necessary by auto NV plus AHUs through floor void in off-peak period. Sometimes over-cooled.	105
17	Inland Revenue, East Kilbride	1995		**Yes. MV ? ac/h**			Floor	Susp'd	Perim	MV	Echelon plan. All orientations. Some atrium stack. Triple-glazed pivot windows with mid-pane blinds, plus motorised hopper windows in most areas. MV has steam humidifiers.	48 50
18	Ionica, Cambridge	1994		**Yes. MV ? ac/h**	See notes		Floor	Exp'd	Via air	MM	Motorised fanlights and atrium vent outlets. Atrium exhaust fan recirculates in winter, boosts in summer. Atrium wind towers enhance exhaust ventilation. Brick flank walls. Termodeck, indirect evap cooling + backup ht pump.	53
19	JEL factory/office, Stockport	1983			**See notes**		Ceiling	Varies		Bespoke	Mechanical transfer of hot air from solar facade to production area in mild weather; hot air exhausted in hot weather. Windows openable at any time.	45 64
20	John Menzies, Edinburgh	1995		**Yes. MV ? ac/h**		Compu-ter rm. Meeting.	Floor	Exp'd		MV	U-shape around central atrium. Windows with sealed mid-pane microblinds. Swirl floor outlets. Night cooling predicted to be seldom necessary in the Scottish climate. Lights switched by area, plus perimeter photocells.	41
21	Judge Institute, Cambridge	1995		**Yes. MV ? ac/h**		Parts naturally vented.				MV	Details to be sought from MFP.	87
22	Leith Academy, Edinburgh	1993		**Yes. MV ? ac/h**		Some added local AC.			Perim	MV	Designed if necessary to convert from educational to other uses, eg: administration or retail. MM to library and laboratories. MV swimming pool. Conflicts with NV and local AC.	55
23	Marston Books, Milton Park	1995	**See notes**					Partial	Perim	Cont	NV with Colt Interactive Window System, motorised (not automated) top pane and adjustable light shelf. Ceiling has grillage to access floorslab mass (for theory see [47]). Floor void + flat roof available for contingency MV/cooling.	46 47
24	Oxfordshire County Hall refurbishment	1993			**Night cooling**	In 15% area AC retained	Perim	Susp'd	Perim	MNV	Induction AC replaced by radiators, condensing boiler and hopper windows (adequate??). Primary air plant for AC system retained for night cooling. Claimed 4 yr payback with 56% drop in elec consumption, 30% gas.	71 88
25	Point North, The Waterfront, Merry Hill, Dudley.	1995	Contingency design.							?		
26	Powergen, Coventry	1995			**MV 1.5/3**	Local ht pump + DX units	Floor	Exp'd	Perim	BV	Two galleries with linear atrium. BEMS-controlled atrium windows. Tempered MV winter, NV with MV/cooling if needed otherwise. Swirl diffusers. LT heat bus for floor, radiant & air htg + heat rejection. Hot eqp't clustered.	28 29 52 105
27	Powys County Hall, Llandrindod Wells	1987								?	Draft article for Buildng Services never published: currently mislaid.	
28	RSPB, Sandy	1997		**Yes. MV 3.5**			Floor	Exp'd	Via air	MV	Sash windows. Ducts embedded in floor slab. Intake via vegetation and underground duct. Bulkhead & atrium extract with heat exchanger.	32
29	Scottish Nuclear, East Kilbride	1994				AC:VRV +Split inboard				NV+SC	VRV in core areas of S and W-facing open-plan offices, Individually-controlled split heat pump units in directors' offices and meeting rooms.	63
30	University of Lincolnshire	1997		**Yes. MV ? ac/h**		See Comm-ents.				Varies	Under construction. Some zones have chilled beams too. Some facades are sealed owing to railway noise. More info could be obtained from RMJM.	33

#	Procurement	Main form (see figure B1)	Nett area (m2)	Main orientation	Glass-glass depth (m)	Facade module (m)	Ceiling height (m)	% cellular	Wall construction	Wall U-value (W/m2K)	Roof type	Roof U-value (W/m2K)	Main glazed walls	Glazing % of main walls	Glazing Type	Frame type	Window U-value (W/m2K)	Upper window	Middle Window	Lower window	Pri solar protection	Sec. blinds	Cross-vent	Other exhaust route	Lighting	Illuminance	Control	Occ m2/p des:actual	*W/m2* Light gains inst:summer	Eqpt gains des:act	Fan pwr hi:lo speed	*Annual energy use: kWh/m2* Heating	HWS	Humidification	Cooling	Fans & pumps	Lights	Small power	Other	Catering	Computer room
16	Public	ATR	7500			3?			Brick					25%	Twin	Al		Hopper	C-pivot	None	L/shelf	Midpane	Yes	Atr roof																	
17	Public	FIN	25000	All	15m	3?	3	10%	Brick						Dble+1			Auto	Pivot	Fixed	Mid V	None		C'ling	HF fluo	500	PE/auto														
18	Prelet	ATR	4000	N-S	Typ 20	1.8	2.8	Small	Curtain	0.25?	M'ptch	0.25?	N&S	75%?	Dble	Al/tim	3?	Auto	T-hung	T-hung	S'bkrs	Int Vs	No	Atrium	HF up	NA	Tel+PE					*Total*	*103*	*kWh/m2*	*estd*	*All-*	*elec.*	*Hearsay*	*actual*	*much*	*higher*
19	O-occ	BLK		N-S																																					
20	O-occ	ATR	4000	All	12	1.5	2.75+	15%?	Curtain	0.4?	Flat	0.4?	All	50%	Dble	Al	3.3?	Fixed	T-hung	None	Mid VB	None	Some	Atrium	Susp HF	400	Cent+IR	Group	13/12?	?	?	Too new	Too new	Too new	Too new	Too new	Too new	Too new	Too new	Too new	Too new
21	O-occ	LIN+GAL																																							
22	Public	FIN																																			*Hearsay*	*energy*	*very*	*high*
23	Prelet	LIN	960	N-S	13.5	2.4?	3	20%?	Brick	0.4	Pitch	0.45	N-S	15%	Dble	Al	3	T-hung	T-hung	Fixed	S'bkr	Roller	Yes	Rflight	Rec fluo	350	PIR	10:?	13.5:?	20:?	NA	*Design*	*figures*	*are*	*faulty!*						
24	Public	T-shape	6000?												Tint+K	Al	1.9	None	Fixed?	Hopper																					
25	Spec	?																																							
26	O-occ	GAL		N-S	12.6	1.2	2.7-3	Small	Brick	0.35	Flat	0.25	N+S	40%?	Dble	Al+tim	3.0?	BEMS	T-hung	T-hung	S'bkrs	None?!	Yes	Atrium	Tel+PE	400	PE+Tel	9:?	15/10?	14:07	NA										
27	Public	?																																							
28	O-occ	LIN	1800	N-S	15m?	3m?	3m	NA	Brick	0.22	Pitch	0.25	N+S?	20%	Dbl E	?	3	U/sash	L/sash	NA	Wall	?	Yes	B'head	HF CFL	275	Phone	?	11:?	15:?	NA	*Total*	*140*	*kWh/m2*	*Estd.*						
29	O-occ	ELL																																							
30	O-occ	Varies																																							

B3 Characteristics of the buildings

B3.1 PLAN DEPTH

Most MM buildings have a plan depth of 12 to 15 metres from outside wall to outside wall or to atrium, though in some designed for *concurrent* operation the depth is increased to 18 m and sometimes much more. However, at depths over about 20 m the openable windows tend to be more for psychological relief.

B3.2 CEILING HEIGHTS

Many MM buildings have relatively generous ceiling heights in the range 2.7 to 3.3 metres and increasingly with exposed or semi-exposed ceilings, sometimes with downstand beams or undulations and additional height into the coffers. It is now becoming generally agreed that it is false economy to attempt to minimise floor-to-ceiling heights: generous heights both enhance the passive ventilation (and daylighting) and provide space to add mechanical systems where required.

B3.3 BUILDING FORMS

Figure B1 is a simple classification of common building forms, with and without atria and conservatories. Each has a three-letter code which is used in Tables B1 & B2. These include:

1 Linear plans, often cross-ventilated. Occasionally (1A) these have a buffer space on one side as a climate moderator or noise barrier. This space need not be continuous: for example a design study of the refurbishment of Temple Way House [94], used added bay windows as both noise barriers and ventilation stacks.

2 Courtyard plans. These are useful, compact forms which permit most of the space to be cross-ventilated. Where there are a lot of cellular offices, the dead spots near the corners of the courtyard can be used if necessary for cores, equipment rooms and so on. The atrium form 2A can be very economical, with added interior space and the roof paid for largely by savings in the specification of the courtyard walls and windows.

3 L-shape. Useful on odd-shaped sites. The corner atrium (3A) although generally less economical than a central one, can be a useful amenity, reception and buffer space on sites not large enough for a central atrium. There are no examples of this in the Tables.

4 Ladder. Two parallel (or nearly parallel) linear strips with cross-links. It is suitable for large buildings over about 10,000 m^2 and can provide sufficient external area for natural ventilation whilst having a more compact internal circulation system than a single courtyard form. Sometimes one or more of the courtyards and re-entrants are roofed-over, as in 4A. Alternatively, there may be a continuous atrium down the middle, with cross-links inside it, as in 4B. We call these “street” (where the atrium floor also serves as the main circulation route) and “gallery” (where most of the circulation occurs around it). Some long buildings (for example the Scottish Office) have combinations of courtyards, streets and galleries in these internal spaces.

5 Block. The plan is often too deep for natural ventilation alone but MM can sometimes help to avoid there being full AC.

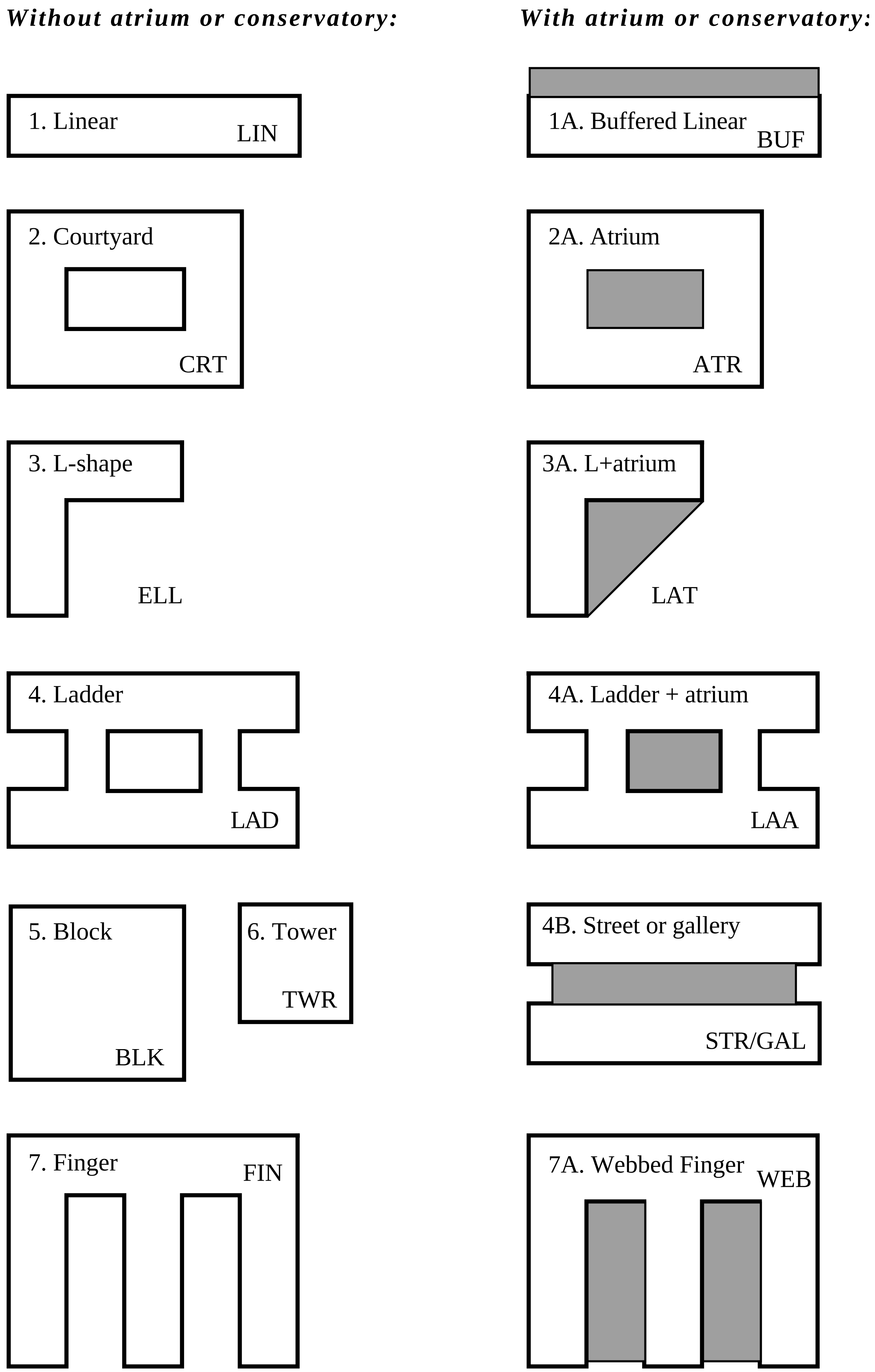
6 Tower. While these are sometimes shallow enough for cross-ventilation, wind effects are often more severe, giving special problems with window design.

7 Finger. A central spine (at the top) has two or more wings running off it. In 7A some or all of the spaces between the fingers may be wholly or partially covered over.

B3.4 ATRIA AND CONSERVATORIES

Atria and conservatories, though still in the minority, are growing in popularity. They can allow buildings to be more compact, provide useful amenity and buffer spaces, and reduce heat losses. They can also assist natural and mechanical ventilation strategies, although there are indications that in atrium buildings - and at least away form the external windows - occupants are less tolerant of increased summertime temperatures than in comparable cross-ventilated buildings: so calculated comfort benefits could be illusory. Atria may also reduce heating, lighting and air tempering requirements, though designers can be too optimistic about this: in practice their success is variable. Effective low-energy atrium design will not be discussed here because a comprehensive publication is currently being drafted for BRECSU [95].

FIGURE B1: SOME TYPICAL BUILDING PLAN SHAPES



B3.5 POPULARITY OF BUILDING SHAPES

The majority of MM buildings identified are linear cross-ventilated (but including some cellular offices), followed by blocks. In the older buildings, courtyard plans were also popular, with its variant the ladder for larger buildings. In the newer ones, the courtyard and ladder are losing ground to the street/gallery, the finger (or its U- or V-shaped principal component), and the atrium. which is also an exhaust air path, for mechanical systems and/or by natural buoyancy, sometimes with wind assistance. In the past there has been perhaps too much emphasis on stack ventilation on still summer days, which are in fact rare in the UK. The atrium form emerged in design studies in the UK in the late 1980s and early 1990s, and was largely anticipated in the naturally-ventilated Gateway II building [68]. The street form emerged from northern European studies and practice at the same time. A few buildings do not fit the classification, for example cruciform and T-shaped local authority offices at Towcester and Oxford which are really just variations on a linear theme. The more unusual forms are:

- The triangular PSI, in which a small central atrium was used very effectively to reduce the apparent depth of the building.
- The cruciform Stockley Park building, with bridging conservatories: at one level a back-to-back cluster of L-shapes, but with complex opportunities for ventilation paths across the building from shaded to sunny atria.

B3.6 TYPICAL MECHANICAL VENTILATION SYSTEMS

In the older buildings, mechanical air supply, when fitted, is most often from the ceiling and sometimes from the floor or the perimeter. In the newer ones, floor supply predominates (this becomes economic when raised floors are necessary for cable distribution), and displacement ventilation may be possible - though this is more often claimed than realised. This can then permit an exposed (or partly exposed) ceiling, which further increases thermal inertia, although direct extraction of heat from the lights becomes more difficult. A few buildings also have ductwork embedded in the structure in order to increase thermal inertia and the effectiveness of mechanical night cooling.

B4 Characteristics of the engineering systems

B4.1 THREE DIFFERENT APPROACHES

In the engineering of the VAC systems, three distinct approaches can be discerned: Traditional, Integrated and Opportunist. These are outlined below.

B4.2 THE TRADITIONAL APPROACH

The mechanical system is designed more-or-less as mechanical ventilation, air-conditioning or comfort cooling for a sealed building, but often somewhat less generously sized or more crudely zoned to take account of the contribution of the openable windows to fine-tuning, to occupant tolerance, or to restricting the operation of the mechanical system to the times and conditions in which it is really needed. This tends to be a relatively expensive approach and perhaps best suited to changeover operation, though concurrent operation is also possible, particularly if it can be done at low fan speed - which can give large savings in fan energy consumption. In Tables B1 and B2 these approaches are coded as follows:

CAC	Central all-air air-conditioning (such as VAV).
DAC	Distributed AC (induction, fan coil, heat pump, spilt) with minimum fresh air.
MV	Mechanical ventilation (typically 4 ac/h or more).

B4.3 THE INTEGRATED APPROACH

The natural and mechanical systems are designed to work together more closely to make up - in a cost-effective, low-energy manner - any shortfalls that might occur if natural ventilation alone was used. For example, mechanical ventilation might be modest in capacity (say 2 ac/h on average), but nevertheless capable of improving air quality in winter; providing additional ventilation to landlocked areas; removing heat from hot areas at source; providing better air movement; and undertaking some night cooling. The coding used in the tables is as follows:

BV	Background Ventilation (typically 2 ac/h during occupancy hours).
BV/MV	Multi-speed ventilation, with a low speed of 3 ac/h or less.
MNV	Mechanical Night Ventilation/daytime natural ventilation.
TC	Trickle-charged (typically 2 ac/h or less, 24 hours, as with Termodeck).
WW	"Whole Works" - elaborate changeover strategies.

B4.4 THE OPPORTUNIST APPROACH

The base building is quite lightly-serviced, perhaps with natural ventilation openings only, as in contingency designs (CON), or with background mechanical ventilation (as in BV or TC above). Where necessary, local supplementary mechanical ventilation or cooling (SC) can be added in a modular form - for example by fan-coils, reverse-cycle heat pumps, chilled beams or direct-expansion units. While recent years have seen some use of relocatable units with quick-release connectors to spine distribution systems, we see be considerable scope for more ingenuity and ultimately some standardisation in this area.

B4.5 FREQUENCY OF OCCURRENCE OF APPROACHES

Representation among the buildings identified to date is as follows:

		OLDER	*NEWER*
Mechanical ventilation	*MV*	*9*	*8*
Distributed air conditioning/comfort cooling	*DAC*	*6*	*5*
Whole works	*WW*	*0*	*5*
Multi-speed mechanical ventilation	*BV/MV*	*4*	*0*
Background mechanical ventilation	*BV*	*1*	*3*
Trickle-charged	*TC*	*2*	*1*
Mechanical night ventilation	*MNV*	*1*	*1*
Central air conditioning	*CAC*	*1*	*0*
Mechanical plus local supplementary cooling	*MV+ SC*	*1*	*0*
Natural plus local supplementary cooling	*NV+ SC*	*0*	*1*
Contingency designs	*CON*	*2*	*1*
Insufficient information/difficult to classify		*0*	*5*
TOTALS		*27*	*30*

B4.6 DISCUSSION OF APPROACHES

The buildings identified are almost equally split between traditional and integrated approaches, with only a few opportunist examples. However, opportunism is also widespread in terms of *ad hoc* additions of ventilation and cooling to naturally-ventilated buildings. In both the older and newer buildings, mechanical ventilation dominates at relatively high air change rates, and fan energy consumption can be high - very high in some instances. After that comes minimum fresh air (1 to 3 ac/h) plus distributed cooling by fan-coils and so on.

While the more integrated approaches are more sparsely represented, in total there are nearly as many as the traditional group. The most significant trend is a move away from multi-speed to whole-works approaches - presumable a consequence of the increased power of computer modelling and of control systems - though experience suggest that the WW strategies may well become simplified in operation.

B5 Some common problems

B5.1 OVER-RELIANCE UPON OCCUPANTS

Some designs expect occupants to react differently with changing conditions: for example if they get hot in mild weather they should open the windows, but in hot weather they are supposed to close them and let the mechanical system do the job. Occupants, however, usually prefer things to work in one particular way and find it difficult (and often do not want) to vary their habitual behaviour in order to satisfy the designer's expectations, let alone to achieve the optimum balance between environmental and energy performance. In addition, they are often poorly-informed, both about how the building works and what they should be doing at any particular time. Some designs also expect individuals to act not in their own interest but for the common good - for example to open windows on the north side of the building to act as air inlets to remove heat from the south. In practice, this is unlikely to happen: people only tend to take control actions once they reach their "threshold of discomfort" [65]. *Designers should seek to make their intended operating strategies obvious, convenient and effective. Where this is not possible, and whilst more deliberate occupant education is desirable, one should also consider means of informing the user - for example an indicator showing that it would be better not to open the window. Occupants should not be expected to take control actions where they personally do not perceive the need for them. They should also not be expected to undertake them too often [72].*

B5.2 INAPPROPRIATE RELIANCE UPON AUTOMATION

To avoid some of the problems with occupant behaviour outlined in B5.1, designers are attempting to automate natural ventilation, and in particular window-opening. While to our knowledge occupant response to such systems has not yet been studied, experience with automatic control of lights and solar blinds [66, 67] suggests that occupants are likely to object to seemingly arbitrary step-changes in system operation, and that automatic control action should be gradual and imperceptible (conversely, response to occupant over-rides should be rapid - preferably immediate - and noticeable!). Perhaps the ideal automatic changeover control takes place when the space is empty (e.g: for night ventilation), or in distant and "unowned' places (for example atrium rooflights). Something which operates in the occupant's own territory and creates a draught (or removes a breeze) is not likely to be welcomed! *Great care - and more study - is required to integrate occupants and control systems effectively.*

B5.3 CHANGEOVER SYSTEMS MAY DEFAULT TO CONCURRENT OPERATION

In the older *changeover* designs already visited, the management had often found *concurrent* operation more convenient or more acceptable (see Section A2.3.2), for example with mechanical ventilation operating at times when natural-only had been predicted, or heated and/or chilled water circulating to terminal units whether it was really needed or not. This is perhaps not surprising in the changeable UK climate, and because people may object to alterations in local comfort contours when systems change their states. Since *changeover* strategies are more widespread in the newer designs, it will be interesting to find out whether this still happens. Recent visits by WBA suggest that it will, and we fear that if anything the tendency of systems to default to ON is becoming more widespread: and the consequences for the buildings' low-energy aspirations may be serious. Indeed, we fear that improved modelling and control systems capabilities may be leading designers to propose operational strategies with a whole range of changeover points. BSRIA's guidance ([105], pages 10-12) is a case in point. We fear that such complex strategies could easily prove to be not only too difficult technically to implement in practice (this is certainly WBA's experience on designs upon which we have been asked to comment), but could also alienate the occupants. *Meanwhile, we suggest that designers aim for simple basic "starter" strategies which can be upgraded as necessary and appropriate as the management gets to understand how the building really works. They should also to avoid excessive energy consumption when concurrent operation happens, for example by giving priority to low-speed operation. If for some reason extended concurrent operation would be particularly unnecessary or wasteful, then control and monitoring systems should be programmed to avoid it, or at least to raise "clash alarms" which rapidly alert management to unnecessarily wasteful operating conditions..*

B5.4 ARE ALL THE FEATURES ESSENTIAL?

For example, *Tanfield House*, an extremely deep-plan air-conditioned building, had openable sash windows at the perimeter. However, only a small proportion of the occupants were near them, the windows could not contribute much to ventilation or cooling, and they also opened not directly to the outside air but to a buffer space ("not real air", as one occupant said). In a recent survey [21] the management (and most but not all of the occupants) did not regard these windows as helpful. Nevertheless, they were potentially valuable as a contingency; and the upper sashes were also used under automatic control as the inlets for smoke ventilation. Such measures could also provide relief and reassurance, so improving the "forgiveness" of the design, see section C5.9. *Further research is required.*

B5.5 PROBLEMS WITH NIGHT COOLING

Often night cooling was not used as the designers had intended, giving higher peak temperatures and/or unnecessary running hours. Peak summertime temperatures hovered near the threshold of discomfort, although with optimum use of the systems (albeit sometimes requiring attention to commissioning, control and maintenance) they could have been lower. Reasons for the shortfall included:

- *Few complaints*. In practice most building managers tend to be driven primarily by the need to minimise bad complaints, rather than to optimise performance. They are therefore unlikely to strive to improve something which occupants regard as acceptably good - or at least not unacceptably bad - even if it could have been significantly better. The conclusion is that it makes little sense for designers to strive to wring the last drop out of system performance if this requires more management attention, and particularly if such measures add complication and run a risk of reducing occupants' tolerance margins or increasing the possibility of failure.
- *Insufficient perceived benefit* for the management to feel it worth running the system.
- *Additional expense (or perceived expense)* of running the systems - often we found poor understanding of the likely impact of an operational decision on energy consumption and cost. For example, one manager was reluctant to run mechanical night ventilation owing to a fear of increasing maximum demand electrical charges. In fact, the fans were very economical at low speed; the MD was during the day; and the MD charges were zero in the summer months.
- *Insufficient zoning:* often systems were designed to cool the whole building - or at least the areas served by a particular plant - without noting that some places might need more cooling than others. It was then impossible to remove enough heat from some areas without others - and typically ground floors - becoming too cool next morning.
- *Operational difficulties:* sometimes controls and interlocks were set up principally for one mode of operation and baulked at another, or at a changeover transition. Most commonly this was a clash between mechanical night ventilation and low limits on supply air temperatures;

These points will influence the guidance and technical recommendations offered.

Durrington Bridge House, which was monitored by BSRIA [105] has alternative natural and mechanical night ventilation. The mechanical system is used in "bad weather": in rain or when the wind was above 25 km/h - which was for about 30% of the monitored period. BSRIA found that the natural system, using motorised hoppers, was just as effective as the mechanical systems, which used the floor void but started-up later to take advantage of night rate electricity and also suffered from heat pick-up. On 25% of the days monitored, however, the building was over-cooled by the night ventilation and boiler preheat became necessary! The mechanical ventilation was seldom needed to meet daytime cooling requirements and BSRIA felt that it might not be necessary if suitable passive winter ventilation could be provided. Alternatively, to reduce energy requirements and avoid heat pick-up, it might be changed to a pull-through system using the natural ventilation inlets and atrium extract fans.

B5.6 OUTSOURCING

Increasingly organisations subcontract their security, facilities management (FM) and plant maintenance to others. Unfortunately, the contracts often do not include operational responsibilities which the designers may have taken for granted - and which may be quite difficult to fulfil without an intimate knowledge of the occupying organisation and what people are doing, almost from minute to minute. Taking examples from two prestige buildings which WBA has surveyed recently:

- The FM contractor subcontracted controls maintenance to a systems house some 20 miles away from the site. The people on site do not even have access to the BEMS time schedules. Needless to say, most of the engineering systems run constantly.
- The design idea in a “low energy” building (completed in 1995) was that occupants telephoned a “help desk” if they wanted the services adjusted - even the lights above their workstations! The FM contract required the help desk to be manned from 0830 to 1730. Any services wanted in the evening cannot be over-ridden manually and so get left on “just in case” until the late night security shut-down after the cleaners leave.

B6 § Conclusions

B6.1 MAJOR THEMES

Clear themes which come through from this review of current practice include the need for:

- Clear strategic approaches;
- Seamless integration of systems which complement each other rather than clash.
- Systems which are not unnecessarily complicated and which do not have unreasonable expectations or make unreasonable demands of occupants and management.
- Avoiding wasteful energy performance, for example by taking care that systems are not too powerful, inefficient, fight each other; or are on too much.
- As part of the above, reviewing the necessary amount of mechanical ventilation. Sometimes it seems to have been over-provided and occasionally it may have been unnecessary, except perhaps locally or as part of a contingency strategy.
- Improving controls: for occupants, for management, and for effective energy-efficient operation.
- Clearer standards and generic exemplars.
- For some types of MM building, perhaps less plant as a permanent (or semi-permanent) part of the building and more which can be readily adapted and exchanged.

For all varieties of MM, simple and ingenious methods of providing the required adaptability could provide inspiration for designers and their clients. Some options have already been outlined in reference [11], but concepts need to be developed, clarified and illustrated.

C PRINCIPLES OF DESIGN AND MANAGEMENT

C1 Introduction

C1.1 WHY CONSIDER MIXED MODE?

This part of the report discusses principles of design and management of mixed-mode buildings and systems. The reviews in Parts A and B suggest that the purposes of mixed-mode designs can be summarised as:

- *Adaptable:* to different occupiers, to changing requirements, to an uncertain future.
- *Usable*, without unnecessary reliance on management.
- *Healthy and comfortable,* but without unnecessary reliance on mechanical systems.
- *Cost-effective*, not wasting money on unnecessary equipment, energy or labour.
- *More sustainable,* with less resource and energy waste and less associated pollution.

The challenge is to stop them becoming mixed-up!

C1.2 IMPROVING EFFECTIVENESS

To combine natural and mechanical systems appropriately to achieve the required results with a minimum of human and natural resource inputs makes sense in societal, commercial and ecological terms. However, this does not mean minimum inputs across the board, for instance:

- more design effort will be necessary in order to help reduce subsequent inputs of materials, energy and management;
- more investment in the building will be needed in order to save on the services;
- although the building services will usually cost less than air-conditioning, investment will be needed to improve their efficiency, responsiveness and adaptability.

C1.3 THE STORY SO FAR

The review in Part B indicates that MM already has a significant presence. Most of the buildings identified work reasonably well, though with some disappointments, particularly in controls and human factors. Energy consumption is often higher than predicted, even for many (though not all) of the newer buildings. Nevertheless, and as reported in the review of BRECSU's office case studies [2], owner-occupiers and government organisations have often obtained buildings which are well-liked, less expensive than alternative air-conditioned designs, and usually lower in energy consumption. Some developers are now dipping their feet in the water: usually - but not always - with pre-lets.

C1.4 DIFFERENT VARIETIES OF MIXED MODE

Few of the MM buildings reviewed fit neatly into a single MFP category. As MM moves into the mainstream *(as is confirmed by looking at a few recent issues of Building Services - the CIBSE Journal),* it is surely right for solutions to be as broad as the imagination. Nevertheless, one can identify several strong themes, including:

- *Robust, simple, upgradeable buildings*, often with heavyweight brick, concrete or stone facade construction, cross-ventilation, insulation somewhat better than Building Regulations, and exposed, or semi-exposed ceilings. Their sophisticated window systems are often fairly modest in area (say 20-35% of external wall) with solar protection and two or more openable elements, the upper of which may be automated, or at least designed to be left open overnight. They are often *contingency* or *zoned* in the MFP classification. Marston Books [46, 47] is a good recent example.

- *Trickle-charged buildings. Concurrent* designs, with very high levels of insulation and permanently-running low-capacity mechanical ventilation with high-efficiency heat recovery. Windows tend to be relatively small in area (15-25%) but high-performance, often triple glazed, low-E, perhaps Argon-filled, and with inter-pane blinds. Perimeter heating may then be unnecessary, as at the Elizabeth Fry Building [56, 69]. While openable, the windows are primarily safety-valves, and a single element - often casement or tilt-and-turn, suffices. Night cooling is available automatically as necessary from the 24-hour running. Additional low-capacity cooling may be provided for enhanced summertime performance by traditional means, groundwater, evaporative cooling (usually into the exhaust air duct with heat exchange), or embedded pipes. The ultimate in trickle-charging is perhaps a sealed unrefrigerated building which doesn't need the windows to open at all, as intended in the New Parliamentary Building [73]!

- *Floor-supply schemes.* In buildings which need raised floors for cable distribution, it is usually practical and cost-effective to use the floor void for air distribution, increasing its depth if necessary. The void may also contain, or allow for, trench heating at the perimeter (usable area lost to perimeter radiators, convectors and terminal units means that many speculative AC buildings don't have perimeter heating, but comfort is usually the worse for it), plus ducts, pipes, and fan-coil or heat pump units underfloor (though these are somewhat inconvenient to maintain). With the services concentrated in the floor, one can expose all or part of the ceiling to improve thermal inertia further, though this makes it more difficult to extract the heat from the lights. Night cooling then becomes important, sometimes natural but usually at least part mechanical in order to help remove heat from the floor void and to cool the incoming air the next day. Sometimes displacement ventilation is attempted, but more commonly "swirl" mixing diffusers are used, probably because far fewer are required, and this works out considerably cheaper. Where windows are opened, the displacement effect also tends to be compromised (though even windows with high and low level openings work partly on the displacement principle).

- *Wind and buoyancy-assisted designs.* Stacks, wind towers, atria and conservatories are added to assist the removal of air. This has led in particular to a new generic building form with a central atrium or street, flanked by office galleries each some 12-18 m deep. In the market, this type of building is in the most direct competition with the air-conditioned model. Consequently, perhaps, it has inherited some of its features - in particular relatively lightweight and highly-glazed external walls and a fairly substantial mechanical ventilation system, often with some cooling. The obligatory raised floor is almost invariably used for air supply. Proposed operating strategies may be *concurrent* or *changeover*, and are sometimes rather complex. Although such complexity may be justified by the size of the building (typically upwards of 5000 m^2 nett), the power of its BEMS, and the likely level of facilities management skills, post-occupancy surveys suggest that it could prove troublesome in practice [6].

C2 Good practice design principles

C2.1 SOME KEY POINTS

Some simple rules for achieving a good and energy-efficient design include:

1 *A good brief*

The best buildings tend to be the product of a good building team/client relationship, with requirements, constraints and aspirations (but not solutions) clearly-expressed in a written brief. The brief can start short, evolve as a record of the progress of ideas, solutions and agreed requirements, and also help to inform third parties and new team members about the purpose of the scheme. The final clear statement of requirements can be refined to assist specification, be referred to in the building contract, and be used to help to ensure that the objectives are met. Part of it can also be incorporated in operation & maintenance manuals. This is difficult for speculative buildings, and while there are ways in which the process can be improved, the market also needs to develop confidence in MM exemplars.

2 *Get the loads down*

Prevention is better than cure! Use building form, orientation and fabric effectively to stabilise internal temperatures and to avoid unwanted heat gains and losses through windows and solid elements. Avoid unnecessary internal heat gains and pollutant inputs by minimising the source strength and providing local cooling and air extraction if necessary. Reduce lighting loads by efficient systems, good control and effective use of daylight. Some common methods are summarised in Table C3.1: this includes many points from reference [8], pages 7-12.

3 *Make good use of passive potential*

Where possible, straightforward “fit and forget” measures are preferable. These include:

- Avoiding unwanted heat losses and gains as discussed above.
- Appropriate siting and orientation of the building, for example turning its back to a noisy road, being distanced by landscaping or car parking, or protected by berms, buffer spaces, or other buildings.
- Developing plan, section, elevation and construction to make good use of natural ventilation, (see reference [1] and other publications) and natural light.

Within the scope of this study, it is impossible to discuss all the available techniques. However, the key issue of window design in MM buildings is discussed in Chapter C3.

4 *Choose appropriate standards*

The imposition of precise but ultimately somewhat arbitrary standards can unnecessarily increase the cost, complexity and energy-dependency of a building. For example, many 1980s offices were unnecessarily AC (or the AC was over-sized) because internal heat gains from office equipment had been grossly over-estimated. Sometimes received standards on temperatures and noise levels - which the client may not even understand - may force designers straight into a sealed building (believe it or not, WBA was asked to comment on one such brief which had been developed for the administration of an organisation dedicated to energy-efficiency!!). It is necessary to seek good information, let the appropriate standards develop as part of the briefing/design dialogue, and where there is uncertainty try to plan for a range and not be dominated by the worst case. MM is well suited to contingency and adaptability strategies, which seek to avoid wasteful over-provision while having appropriate robustness to guard against irreversible failure. Essentially, it becomes a form of insurance.

5 *Comfort is context-dependent*

Comfort standards are also not absolute: different people prefer different things and some fine-tuning is desirable. Standards must also be kept under review as the design develops, because the design solution and management style proposed may also influence what is appropriate. Looser standards may suit where people to have the opportunity to alleviate discomfort quickly and simply when it occurs, for example by closing a blind, opening a window, adjusting a thermostat, taking off a jacket, moving their seat or screen, or lifting the telephone - at least if the facilities manager or automatic system at the other end is able to respond rapidly [5].

TABLE C1		GETTING THE LOADS DOWN		
	ITEM	***ACTIONS***	***CAUTIONS***	***COMMENTS***
1	Reduce fabric heat losses.	Better insulation.	Building more self-heating. Could be problems with winter draughts.	Better ventilation and cooling required.
2	Reduce infiltration heat losses.	Better airtightness.	Needs careful detailing, site quality and preferably pressure testing.	Controlled ventilation needed to replace lost infiltration.
3	Reduce fabric heat gains.	Light coloured finishes.	Preferably not metallic sheen.	Ventilated rainscreen?
4	Introduce time lags to fabric gains.	Massive wall construction.	Some internal mass desirable.	Less responsive to heating.
5	Reduce unwanted solar gains.	Simplest (and quite common) to use facade orientatiion within 30° of N-S.	Avoid north side being gloomy.	Solar control is easiset to South. WSW and W orientations most difficult:high gain late in day.
6	Reduce unwanted window gains/glare	Modest window area.	Needs careful treatment.	Splayed reveals etc.
6.1		Consider internal blinds.	Little reduction in heat gains. May obstruct operation if inward-opening.	Some kind of adjustable blind is usually essential, particularly where there are VDUs. They may block ventilation.
6.2		Consider fins or overhangs.	Daylight and view restricted.	Often needs blinds too.
6.3		Consider mid-pane blinds.	Don't suit all window types.	Often a practical choice.
6.4		Consider external blinds.	Expense. Maintenance. Problems in winds and at turbulent corners.	Most effective. Auto control disliked in office areas: provide over-rides.
6.5		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.
7	Review occupancy gains.	Use realistic figures. 14 m2/person common today.	There may however be clusters of higher density.	Can clusters be dealt with as exceptions, eg: by redistributing capacity or using add-on modules?
8	Reduce heat gains from lighting.	Don't over-light: 350 lux in VDU offices? Less in circulation areas etc..	Some people may require more: consider adjustable or task lighting.	Design for appearance. Not just desktop illuminance.
8.1		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/m2, preferably 10 W/m2.
8.2		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.
8.3		Avoid lighting use when people are out or daylight is sufficient.	But maintain pleasant environment for those who remain.	Avoid switching-on of unnecesssary lights. Aim for less than 50% use on hot days.
8.4		Provide effective lighting controls	With good manual over-rides.	See reference [67].
8.5		Exhaust heat from luminaries.	May need suspended ceilings etc..	Best to minimise lighting loads.
8	Reduce internal gains from office equipment and other appliances.	Select low-energy equipment.	Seldom a building design decision.	Nevertheless well worth advocating!
8.1		Avoid equipment being left on unnecessarily. Select auto-slumber equipment if appropriate (but check standby load and switch it right 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 than much modern equipment is never switched right off: avoid this if possible.
8.2		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, comms..
9	Spread the load over 24 hours	Expose thermal mass of ceilings etc. to reduce temp. swings.	Heat needs to be removed overnight. What if extended occupancy?	Can stabilise radiant temperature. Needs natural and/or mech night cooling systems.
			Winter preheat time and energy consumption may be extended.	Usually a minor problem. Possible spur to superinsulated, trickle-charged designs.
9.1		Expose thermal mass of floors.	Usually needs ventilated raised floor.	Cautionary points discussed later.
10	Avoid general defaults to ON	Consider presence/absence detection.	People may not like it. Presence detection may bring systems on unnecessarily.	Finesse required. See [74].

6 *Service the remaining loads effectively*
Where possible, choose the simplest and the most efficient means of doing the job, and consider ranges and probabilities while developing the design. Engineering techniques need to be developed to deal better with variable and diversified ventilation and cooling loads - as happens for electrical systems. Where possible, systems should be designed to be self-balancing and able to be adapted easily to changing patterns of load - for example to accommodate an area with an above-average ventilation requirement perhaps by slightly “robbing” nearby, less-demanding areas. Note that there are many aspects to in-use efficiency: not only the efficiency of the item, but also the efficiencies with which the item follows the load, and the the load follows the demand (see chapter D4). If possible, local and abnormal requirements should be serviced separately, or otherwise large systems may have to operate wastefully to look after them: the *tail-wags-the-dog* syndrome! Remember that the lowest-energy state of most active systems is OFF!

7 *Control and manage the systems effectively*
This means systems which not only work well in the engineering sense but are understandable and usable by occupants and management. Usable controls should be visible and readily accessible to occupants, where possible at the point of need; easy to use; and clear - preferably intuitively obvious - in what they are doing. The outcomes of any control action should also be rapid and unambiguous. Similar principles apply to manageability, although at a different scale. Some general principles are discussed in reference [66] and a classification of users and spaces is considered in reference [67]. An important objective is to avoid systems defaulting to ON, which all-to-easily becomes their most convenient operating state.

8 *Include appropriate facilities for metering and fault-detection*
Management need to be able to review performance against their 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 in offices to computer rooms, restaurants, and large car parks) and to suitable cost centres. In spite of comprehensive fault detection on today’s BEMSs, to date very seldom have these included performance monitoring against design and management objectives for the system. For example, for mechanical night cooling it would be useful to know whether the supply air was coming in more than say 3°C above outside air temperature - as it often did in monitored buildings [8].

9 *Have an effective handover*
It is well known that pressures for handover often squeeze building services commissioning programmes, and that systems and controls are not checked and tuned in the ways that the engineers had intended. Whilst adding to the pleas for effective commissioning, it is also important that the industry aims to deliver robust, adaptable MM systems which are made as easy as possible to set-up, to fine tune and to alter. In addition, the design 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. Requirements to be written into outsourcing contracts also need to be made clear. If possible there needs to be a contingency fund to undertake “sea trials” and to pay for any small alterations which are likely to prove to necessary once the building comes into use.

10 *Don’t be too clever!*
Avoid unnecessary complication. Simple and straightforward solutions often work best. In attempting to optimise the design, one should take great care to consider the downside risk of improvements which offer only marginal benefits, particularly where they require high levels of input by the operator, or place unrealistic expectations upon the occupants.

C3 WINDOWS IN MIXED-MODE BUILDINGS

C3.1 INTRODUCTION

Windows and other natural ventilation openings are important and often complex components of NV and MM buildings. Not only must they fulfil the ventilation requirement without admitting excessive amounts of noise, rain, dust or insects, but they also needs to be durable, secure, look good, provide a view, admit daylight, control glare and solar gain, and limit unwanted air infiltration and heat loss. Sometimes these features can clash, for example with blinds obstructing the air path.

C3.2 THE NEED FOR AND EXERCISE OF CONTROL

Most of the above tasks also require a high degree of control: usually manual but increasingly motorised and sometimes automatic. An important issue is who controls what and how. Recent studies [27, 65, 66, 67, 72, 74] suggest that:

i People will tend to do what is easiest and closest to hand, for example they will be more likely to open the lower window if the upper one is less accessible, or to switch on the light rather than raising the blind. If possible, designers should endeavour to make the action they desire the most obvious and convenient one for the user. If this is not possible, a different system or some form of automation may be desirable.

ii In open-plan spaces, people immediately beside the windows tend to feel significantly more comfortable and in control than other occupants. Even where arrangements are made for those inboard to reach their window and operating mechanisms easily, they frequently feel inhibited in doing so. Furniture layouts with desks under windows make access to the window difficult for anyone, even the occupier of the desk.

iii Adverse effects of windows, and in particular glare and draughts, are most felt by the people more remote from them, who are both less in control and may be affected by several, some of which may also be quite distant from them and their immediate working group. To improve conditions and to alleviate discomfort, remote control of upper windows and blinds from inboard workstations needs more consideration. This may also permit automation to enhance performance, particularly outside normal working hours.

iv Occupant surveys indicate that automatic control of blinds and lights is resented if their operation is perceptible and rapid [67]. We think it very likely that there could be a similar occupant response to automatic control of windows for ventilation, though this needs to be reviewed. Where such control is applied, the provision of suitable and accessible over-ride facilities for occupants is essential.

v Automatic blinds and lighting control have seldom been interlocked. This has caused lights to be switched off when blinds were also shut, and consequently most or all the lights are often kept on whatever the daylight. Modern systems where individual luminaires dim in response to local light levels can help to resolve this problem, but appropriate system settings are not easy to determine.

vi People tend not to take control actions until they experience a *crisis of discomfort [27]*. Then they require rapid, preferably instant, response. From the engineering point of view, individual action is often rather extreme and too late. For example, mechanical night ventilation in the BRE Low Energy Office did not reduce peak temperatures as much as predicted, because with the cooler start people delayed opening their windows until later in the day, by which time the outside air had little or no cooling effect.

vii Inertia in individual and particularly group behaviour not only reduces comfort but often also wastes energy. For example, in an open-plan office, once a blind has been lowered to counteract glare, it tends to stay down. Sometimes this inertia can be an advantage, as when windows opened during the day remain open and so provide night cooling, as at NFU [58]. However, such windows need to be secure, and often separate from the main window, or they will be shut by cleaners, security, or possibly the occupant when leaving the building. One also needs a means of shutting them if the building gets too cool. Good security guards do this, but they seem to be increasingly rare: perhaps another consequence of the outsourcing culture. Such operation can also be very labour-intensive.

C3.3 WINDOW SYSTEMS FOR VENTILATION

Chapter 4 of reference [1] contains a review of ventilation components, which will not be repeated here. Instead we concentrate on how these components can be, and have been, brought together to serve different purposes in windows in MM buildings.

C3.4 PURPOSES AND METHODS OF VENTILATION

Purposes and methods of ventilation were summarised in Table A3.1. The following are most appropriate for natural ventilation:

V1 Background (trickle) ventilation.
V2 Daytime ventilation and cooling (this may need different elements for local and for cross-ventilation).
V3 Night ventilation and cooling.

Usually high and low-level openings will be desirable to promote single-sided ventilation, for example in a cellular office. These may either be two separate elements, or be combined in centre-pivot, sash and sliding projecting windows.

For each purpose there are three main choices in MM buildings:

i Whether to use natural and/or mechanical systems.
ii If natural, whether manual and/or mechanised and automated.
iii Whether a single window element can undertake several of the required functions.

C3.5 HOW MANY VENTILATION ELEMENTS SHOULD A WINDOW HAVE?

For straightforward usability, there is much to be said for each function being assigned to a separate element: say an unobtrusive trickle ventilator; a readily-operable main window- preferably with high- and low-level openings, and an identifiably separate, secure, weathertight and possibly mechanised and automated element for night and cross-ventilation. To reduce capital costs, one wants as few elements as possible, and it may be difficult to justify elements which duplicate a function which the mechanical systems present are able to do - except perhaps as part of a contingency strategy.

C3.6 MM WINDOWS IN PRACTICE

To attempt to undertake all three functions naturally using a single-element window tends to work in small rooms only - and then often not very well. In multi-occupied spaces, and where there is cross-ventilation, limited controllability usually becomes a problem. In practice, many MM buildings have two-element windows, commonly:

i At high level (or occasionally at low level) small hopper, top-hung or sliding-projecting fanlights, or centre-pivot louvres. These are used variously for cross-ventilation, night ventilation and background ventilation, and usually have some form of mechanical operating mechanism. In MM buildings completed in the last two years, some have been motorised and frequently automated, the exception being Marston Books. Motorised gear can offer finer control at small openings than most manually-operated equipment. Under suitable control, automation can give a better distribution of air in the space, as all windows can be opened a little bit. Under manual control is it more likely that a few will be open a lot.

ii Underneath, and usually in the vision zone, larger centre-pivot, vertical sliding sash or top-hung windows. During the day these are used as the occupants wish. The standard ironmongery for centre-pivot and top-hung windows often also has secure night ventilation positions. Potentially, double-hung vertical sliding sashes can undertake both functions (i) and (ii). However, in practice the top sash is often difficult to reach and to operate, and therefore under-used: some form of remote manual or motorised control is often desirable, but very seldom provided.

Occasionally the windows also have fixed vision panels underneath or in between them.

C3.7 WINDOWS IN BUILDINGS DESIGNED FOR CONCURRENT OPERATION

Some systems designed for *concurrent* operation - for example Refuge House, Solid State Logic, and the two buildings at the University of East Anglia - have only single-element windows. Here presumably the design intention was that the mechanical systems would do most of the job (controlled ventilation in winter, cooling air in summer, and pollutant and unwanted heat removal at all times) with the windows being primarily for psychological relief, emergencies, short periods of rapid ventilation, and perhaps to provide a breeze on still, summer days.

C3.8 TRICKLE VENTILATORS

In the MM buildings studied, trickle ventilators are rare. Often they are redundant because the mechanical systems provide the required background ventilation. At other times they have been deemed unnecessary. EnREI surveys also revealed that occupants may not understand them - though once their purpose had been explained by the surveyor the occupants used them more effectively: simple education can bring great benefits! However, in well-insulated well-sealed buildings with significant internal heat gains the main windows may not be able to provide well diffused, draught-free background ventilation in cold weather:

i They may not be opened sufficiently, and less air will get in by infiltration than people anticipate from traditional practice. This may not matter if the occupants regard the air quality as acceptable, provided that there are no insidious pollutants which they can not sense.

ii If they are opened, there may be more draughts because the air inlets are more localised. With reduced fabric heat losses in better-insulated buildings, more ventilation will also be needed to carry away any excess heat which before would have been lost by conduction, and there will also be less vigorous heat output from radiators etc. to temper the draught.

On the other hand, and as mentioned in [46], trickle vents left open cause energy wastage overnight and extend preheat periods, although one can obtain self-actuated temperature, pressure and humidity sensitive ventilators which provide some degree of passive control. In buildings that are naturally-ventilated in winter, there may also be a case for automated trickle ventilators. Sometimes it may also be desirable to bring in the air behind the perimeter heating, as more frequently happens in Northern Europe.

C3.8 WINDOWS AND PLANNING MODULES

In owner-occupied, pre-let and public sector buildings, occupiers have a clearer knowledge of their needs[2]. In such buildings is is often possible to use larger planning modules - see Tables B1 and B2, where values between 2.4 and 3.6 metres are common. This scale permits discrete tall windows, which can provide good views and daylight distribution, and incorporate traditional devices such as splayed reveals to increase apparent width, improve sight-lines and reduce contrast glare (though in practice splays may be obscured by curtains and blinds - which may or may not have a similar effect). The areas of wall between the windows are useful, for example, to park curtains, as a backdrop to VDU screens, and to illuminate at night to improve the appearance of the interior.

C3.9 WINDOWS IN SPECULATIVE DEVELOPMENTS

Speculative developments usually require a finer module to suit uncertain internal planning requirements, as is also evident from Tables B1 and B2. In the late 1980s, some letting agents' preferred modules were as small as 1.2 or sometimes 0.9 metres. However, this became regarded as too fine and today's BCO specification [24] recommends 1.5 m. To have one window for each module of this size can create rather fussy and repetitive elevations: and although sometimes alternate modules can be glazed, continuous bands of "ribbon" windows (or ribbons with every fifth or sixth module opaque at the column line) are favourite solutions. However, to stop these these becoming rather mean "vision slots" the window area often climbs above the "safe territory" 25-30% of wall area - with consequent problems of solar gain, and a tendency to lightweight, curtain walled construction, with heat-reflective glass and often increasing the need for mechanical cooling. If natural ventilation is used, then quite elaborate external solar protection may be needed: sometimes this in not practical or affordable - not only because of its capital costs and maintenance requirements, but also on account of town planning regulations, in respect of both appearance and plot ratios based on gross external area.

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2 Though with less certainty today than a few years ago. Sometimes the building procurement system (unwittingly or deliberately) also takes little account of their views

C3.10 DAYLIGHT, BLINDS AND SOLAR CONTROL

A useful rule of thumb is that daylight will only be adequate at points from which the sky can be "seen", so potentially the most useful daylight comes from the top of the window, and glazing below desk-top level is virtually useless. Unfortunately, however, sky and sun through the top of the window can be powerful sources of glare. In traditional situations with rectilinear plans and paper-based based tasks one could achieve satisfactory relationships, at least for most of the time. However, with VDU screens the problems of both reflected glare and high illuminances means that daylight, sky and sun glare often has to be controlled [90].

C3.11 WINDOW CONTROLS

The degree of control appropriate will depend upon the tasks the window need to perform, and the people who are affected by it. The main controls required will be of ventilation, solar gain and glare/radiation/privacy. It is usually best for the final group of functions to be under individual occupant control, either using a supplementary device or an over-ride facility on any automatically-controlled blinds. Sometimes blinds and ventilation clash. Essentially:

1 The person beside the window needs to feel in sufficient control of it. This means being able to exercise both fine and coarse control functions, and to choose whether or not they sit in the draught. It should be simple and straightforward for the occupant to make all the adjustments the designer anticipates will be necessary. This may need remote control facilities, especially for high level fanlights etc..

2 The person remote from the window seldom feels in much control of it. This tends to introduce high inertia into the system: nothing changes until the *threshold of discomfort* is reached. There is then often a violent state change - for example a window is opened wide or a blind is lowered. This is then followed by a more inertia until someone else becomes really uncomfortable and makes another state change. At the end of the day, or the beginning of the next one, the windows and blinds may be returned to their normal default state by the occupant, cleaning or security staff but frequently they stay where they are until someone else finds the situation intolerable and intervenes.

3 Some things are better motorised and controlled automatically - but where possible with local manual over-rides - and this often applies to high-level windows. Potentially the automatic systems can set the necessary default states, provide supplementary features such as the control of natural night ventilation (or natural make-up air for a mechanical exhaust system), and over-ride control by people deep into the office - who are often inconvenienced by glare and draughts from upper windows.

C4 INTEGRATING NATURAL VENTILATION AND MECHANICAL SYSTEMS

C4.1 THREE FORMS OF INTEGRATION

Section B4 identified three forms of integration:

1. Traditional. Where the mechanical system is designed more-or-less as mechanical ventilation, air-conditioning or comfort cooling for a sealed building.
2. Integrated, where the natural and mechanical systems are designed to work together more closely - for example with mechanical night ventilation; or top-up cooling under very hot conditions.
3. Opportunist, where the base building is quite lightly-serviced, and extra mechanical systems are added when and where necessary. At the minimum, this is the *contingency* approach with no mechanical systems at all.

WE HAD HOPED TO WORK UP SOME OPTIONS FOR THESE SYSTEMS IN DETAIL, BUT THERE HAS NOT BEEN TIME SO FAR, AND INDEED THIS MAY BE MORE APPROPRIATE FOR THE NEXT PHASE OF THE WORK.

C5 Comfort and control

C5.1 THE AMBITION

MM systems endeavour to deliver the best features of naturally-ventilated and mechanically-conditioned buildings. The level of ambition will of course vary with the system adopted: for example one would not expect a naturally-ventilated *contingency* design to deliver more than a naturally-ventilated building (though the MM design might possibly be better thought-through) but one might expect *complementary* designs to.

C5.2 THE BEST OF BOTH WORLDS?

In a complementary design, one might reasonably hope to combine the closer control achievable by mechanical systems with the passive potential (at least in mild weather) and the wider tolerance margins that occupants have where they can open the windows. This could permit:

- Better air quality in winter (and less dusty, particularly in summer) owing to mechanical background ventilation and local extraction of heat and pollutants, and improved ventilation efficiency (for example with displacement ventilation).
- Better thermal comfort in winter owing to the absence of draughts from windows.
- Better thermal comfort in summer owing to heat removal by night ventilation, possibly coupled to fabric energy storage, and potentially higher air velocities with agitation by the mechanical supply.
- Widened occupant tolerance of environmental conditions in all seasons owing to the ability to open windows.

C5.3 THE WORST OF BOTH WORLDS?

On the other hand, one might fear:

- Poorer air quality owing to pollutants introduced by the mechanical ventilation system.
- Discomfort from difficult-to-control air movements from the mechanical system.
- Unwanted heat gains in the mechanical system.
- Clashes in performance between the natural and mechanical systems.
- Uncertain occupant attitudes and perceptions.
- Unrealised ambitions owing to system, control and management faults.

C5.4 SOME EMPIRICAL EVIDENCE

To date there have been few studies of comfort and control in MM buildings, but we have obtained a small amount of information from Building Use Studies' Ltd's (BUS's) database of occupant questionnaire survey findings in 54 buildings, largely offices. The sample includes 4 MM buildings. One of these is a naturally-ventilated contingency design. The other three are concurrent designs with relatively high air change rates of 4 to 6 per hour: two with mechanical ventilation and one with underfloor VAV air-conditioning. The sample also includes four buildings with "advanced" natural ventilation (ANV), all but one incorporating tall spaces with stack and/or wind-assisted exhaust ventilation.

C5.5 OVERALL COMFORT

C5.5.1 Figure C5.1 is a distribution curve of average overall comfort score (on a seven-point scale from 1=unsatisfactory to 7=satisfactory) versus percentile. The continuous horizontal line at just above 4 (actually 4.04) represent the median score, and the dotted lines above and below it the 25th and 10th percentiles.

C5.5.2 Previous analysis of this distribution curve (then with a smaller number of samples) revealed that in terms of occupant perceptions of overall comfort there was little to choose between NV and AC buildings, although both the best and the worst examples in the distribution tended to be air-conditioned [99]. Similar conclusions have emerged from recent studies by BSRIA and the University of Wales/University College London.

C5.5.3 The new buildings however tell a different story, with overall comfort in the MM buildings tending to be in the upper quartile and with all but one of the ANV buildings being well below the median. Before too much is read into these findings - which are on the verge of being statistically significant at the 5% level - one must point out that the solutions are very diverse and that previous studies [e.g: 88, 99] have underlined the importance of the management dimension. The ANV buildings required more effort on the part of occupants, management (and indeed designers and contractors) to work well, while the MM buildings with *concurrent* operation had more power to spare, albeit often at the expense of some of their claimed energy-efficiency (only the *contingency* example in these surveys was good in this respect). The MM buildings in the BUS sample - with the exception of the least comfortable one - also had more responsive and service-driven facilities management than the ANV buildings.

C5.5.4 Of the four MM buildings, interestingly the complementary designs with *concurrent* operation (of mechanical ventilation without chilling) were less comfortable. The technical surveys revealed that there were good reasons for this: in the worst the management and maintenance was poor (being organised from a central BEMS station in head office several miles away) and the mechanical systems were not operating as designed, even though the BEMS and its operators said that they were! In the other, design and commissioning faults meant that the ventilation air was considerably warmer than that outside - typically by about 3°C and night cooling was not effectively operated - so the indoor temperatures were considerably higher than they should have been. It is instructive that the simple, open-planned (with few cellular offices) naturally-ventilated *contingency* design around a central courtyard performed so well from the occupants' point of view. This casts some doubt on the claims for advanced natural ventilation in many offices (and possibly the need for it, though ANV can allow buildings to be deeper in plan). The best building (though only just) for overall comfort was a deep-plan office with AC and openable windows. However, given the good performance of the *contingency* design, one wonders whether all the effort was justified, particularly because the AC building was in a cooler part of the country, and its energy consumption was high!

FIGURE C5.1
DISTRIBUTION OF OVERALL COMFORT SCORES   *Source: Building Use Studies Ltd*

C5.6 SUMMERTIME TEMPERATURES

Figure C5.2 shows a similar percentile plot of summertime temperatures. Again, the ANV buildings perform relatively poorly. The poorest MM example was the one with the technical and management faults.

FIGURE C5.2
DISTRIBUTION OF SUMMERTIME TEMPERATURE SCORES Source: BUS Database

C5.7 AIR QUALITY

Figures C5.3 and C5.4 show summer and winter air quality. For the MM buildings, the summer air quality and temperature rankings are very similar, though one of the ANV buildings rates highly in both summer and winter. In winter, the *contingency* MM building does not perform quite so well, perhaps justifying calls for controlled background ventilation. One *concurrent* MM design does quite poorly in winter, perhaps because it has local downblow fan-coil units with partial recirculation.

FIGURE C5.3
SUMMER AIR QUALITY *Source: Building Use Studies Ltd (BUS)*

FIGURE C5.4
WINTER AIR QUALITY *Source: Building Use Studies Ltd (BUS)*

C5.8 CONCLUSIONS ON OVERALL COMFORT

Although the sample is small and more information is required, the results are encouraging: MM buildings of several varieties do seem capable of delivering above-average performance on overall comfort - albeit often at some additional energy cost (though not in the *contingency* design). Anecdotal experience from other MM buildings suggests the same and - although not using comparable questionnaires - BSRIA's survey results at the MM Refuge House were also relatively good [102]. However, some of the benefits of MM may be related to the motivation of the procurer and of the occupant as much to the building and system type itself. It may also illustrate the relative robustness of the concept in relation to ANV.

C5.9 FORGIVENESS

"Forgiveness" is an index under development by Building Use Studies Ltd (BUS) and WBA to attempt to identify the degree to which people are prepared to accept the conditions in their building. For example, if the building is attractive, congenial or well-managed, or responds rapidly - even if not entirely effectively - to requirements, one might expect occupants to give it the benefit of the doubt. The simple index we are working with to date is the ratio of the overall comfort score, on a 7-point scale, to the arithmetic mean of the individual scores for winter temperature, summer temperature, winter air quality, summer air quality, noise and lighting. Hence a forgiveness of 1.1 means that the overall score is 10% higher than might have been anticipated. Figure C5.5 shows the distribution curve for forgiveness. Extraordinarily, the three[3] MM buildings are at the very top of the range (although BUS tells us that they have just been topped by a new entry to the database) whilst the ANV buildings, although still forgiving, are nearer the middle. The most forgiving building is the *concurrent* design with the disappointing mechanical ventilation system (see C5.5.4): here influences such as the control and management of the building, the presence of opening windows, or the general ambience appeared to have been having a very positive mitigating effect.

FIGURE C5.5
FORGIVENESS *Source: Building Use Studies Ltd (BUS)*

3 Unfortunately, forgiveness scores are only available for three out of the four buildings of each type: in the other two, one question used was slightly different, making the results not strictly comparable.

C5.10 CONCLUSIONS ON SUMMERTIME TEMPERATURES

Whilst the performance of the MM designs is variable, the ANV examples are uniformly disappointing both in relation to the median and to the contingency MM example. Why might this be? The work of Humphreys in the 1970s [100] revealed that occupants of "free-running" buildings tended to prefer indoor temperatures which varied in relation to those outdoors, while in sealed buildings their preference fell within a fixed and more limited range. This and similar work has been used, correctly in our view, to justify more relaxed internal temperature standards in naturally-ventilated buildings. It appears that this tolerance is a consequence of both psychological and physiological dimensions, for example:

- i In schools, Haigh [65] found that people put up with the environment they had until a threshold of discomfort was reached.
- ii In offices, similar behaviour was detected[5]: once uncomfortable, people wanted rapid response: it did not matter how they got it. Moving about, adjusting a window, twiddling a knob, or ringing the manager all seemed to be equally good at improving perceived control - provided that the response was rapid and effective..
- iii Baker and Standeven [101] identified other fine-tuning processes which they termed *adaptive opportunity*.

The issue seems to be that where people become uncomfortable and lack both adaptive opportunity and rapid response, their tolerance range for environmental conditions narrows. This applies to all buildings, not just AC ones. It seems that several ANV and MM buildings could have fallen into this trap: in seeking to reduce summertime temperatures, the measures promoted have also unwittingly decreased occupants' adaptive opportunities and tolerance margins! A recent study by Oxford Brookes University at the Open University [27] has revealed that even in a shallow-plan space, the comfort perceptions (and probably tolerances) of those beside and just one seat away from openable windows differ significantly.

C5.11 CONCLUSIONS ON AIR QUALITY

The best buildings for summertime air quality were the more traditional MM types: the AC building with the openable windows available (though in fact not much used) and the NV *contingency* design. However, in winter the NV design was not so good - although just above the median - presumably because it was difficult to adjust the windows effectively (they did not have trickle ventilators and a night ventilation position was only added after experience in use).

The *concurrent* designs, other than the AC one, did not perform very well either in winter or summer, although both did have design and management faults. The fairly substantial (4 to 6 ac/h) mechanical ventilation systems therefore do not seem to have been very helpful investments. Since neither building had more exacting plan depths, occupation densities, office equipment gains or external noise levels than the NV *contingency* design, it might have been better for them to have pursued the *contingency* route and put the money saved into the better windows, solar control, lighting efficiency, and lighting control that the *contingency* design had! Alternatively, a low-power, low-volume, full-fresh-air trickle-charge system might have been sufficient, and possibly better.

C5.12 GENERAL CONCLUSIONS

While MM buildings generally appear to be delivering better comfort than average, this may be more a consequence of the attitudes of the managements that procure, occupy and look after them (and their staff), and the design teams that respond to them, than necessarily of the buildings and their engineering systems alone. While the sample size is small, it sows some seeds of doubt about the need for (and performance of) the higher-powered *complementary* designs with *concurrent* systems. More modest installations in simpler buildings may be just as good, and even preferable.

C6 Operation, management and maintenance

C6.1 A POTENTIAL PROBLEM

In attempting to combine the best of passive and active measures, MM systems are different and potentially more complex in their operation. However, recent studies are beginning to reveal that many buildings fail because they are too complicated and provide too much of a burden for management.

C6.2 DOES MM MAKE THINGS SIMPLER OR MORE COMPLICATED?

Sometimes MM can make operation simpler, for example with:

- a *contingency* strategy adopted and some mechanical systems avoided;
- openable windows available which help to increase occupants' tolerance of internal conditions and allow them to resolve some of their own comfort problems without involving management;
- simple *concurrent* operation - for example in a trickle-charged design - increases stability and provides some power to spare; and
- demand-activated *changeover* -for example with window-linked switches or comfort cooling on interval timers - allows systems to be shut-off or boosted, and waste avoided, without explicit management intervention.

However, the more elaborate *changeover* strategies can be confusing for management and sometimes for occupants, so perhaps it is not surprising that they often default to *concurrent* operation, and too often in the highest-energy state.

C6.3 DESIGN FOR MANAGEABILITY

While many systems are capable of fine-tuning, it appears to be important for designers to offer simple, robust, manageable, energy-efficient strategies which will achieve most of the objectives without making too many demands upon management. Skilled managers can upgrade these as necessary to higher levels of performance and efficiency as they gain confidence and experience in operating the building. If such a start-up (and fallback) position is not established, then the systems may easily default into much less desirable states, often with items that are marginally necessary running permanently. Some problems of this kind are discussed in Section D4.

C6.4 THE FANTASY OF FLEXIBILITY

Clients and designers are often tempted to seek systems which offer near-infinite flexibility. These can easily become expensive and technically elaborate, and still fail to meet the full range of requirements that materialise. Meanwhile, the routine effort of looking after all the technology usually absorbs a lot of time. A more straightforward, adaptable MM system could well require much less effort, even including special attention to re-configure it (physically or operationally) to changing requirements. However, the effort it does need may be less routine and more difficult to mobilise. For manageability, systems with straighforward adaptability are therefore important goals.

C6.5 THE OPERATIONAL RESPONSIBILITY

Many organisations do not differentiate clearly between operation - making the system work effectively from day-to-day and minute-to-minute, and maintenance - making sure everything is in good order, clean and working properly. Appropriate job descriptions need to be made clear before staff are appointed and maintenance and/or facilities management contracts let.

C6.6 MAINTENANCE REQUIREMENTS

While MM systems are often simpler than full air-conditioning, because elements may be operated only occasionally or intermittently it will be important to check them thoroughly at the appropriate intervals, to test their controls, and to clean them if necessary. Automatic checks on performance and malfunctions are also desirable to ensure correct operation without wastage.

PART D RELATED ISSUES

D1 Introduction

D1.1 This chapter outlines some other issues which may affect the uptake and performance of MM buildings and systems. These include marketability, cost-effectiveness, energy and environmental issues, and health benefits - each of which has its own section.

D2 Marketability

D2.1 INTRODUCTION

The market does not at present really understand what is meant by mixed-mode. However, interest, knowledge and understanding are now growing rapidly as the demand for "greener" buildings increases and more MM buildings are completed, publicised, monitored and discussed. MM buildings have been produced for over 20 years, either in response to specific briefs, or owing to the interest and enthusiasm of at least a few members of the client or building team. As combinations of natural and mechanical systems move into the mainstream - at least in temperate climates such as the UK's - we think MM will be regarded as completely normal and to labour the point could become unnecessary, and even counter-productive.

D2.2 PROCUREMENT AND TENURE PATTERNS

The older exemplars of MM buildings in Table B1 were built almost exclusively for owner-occupiers and public sector clients. The newer ones include a number of pre-lets: developer buildings influenced by market standards but where occupiers are identified before construction starts and participate in the briefing and design process. Surveys by Building Use Studies Ltd (some were reported in [5]) indicate that pre-letting can produce buildings (including MM ones) which are more energy-efficient and higher in occupant satisfaction than not only speculative buildings (which is perhaps hardly surprising) but also than owner-occupied ones.

D2.3 THE SPECULATIVE MARKET

D2.3.1 Speculative examples of MM are rare. In spite of their potential appeal to a wider market, they are not yet industry-standard products and everyone is fearful of the unknown. As a developer said at a recent conference [75]:

> "Green buildings with natural ventilation, non-divisible office space and lower lighting levels are only feasible for owner-occupiers with fixed requirements. For speculative schemes, you have to accommodate unknown users.......Institutional investors don't want to take risks on temperatures and IT loadings. Nevertheless, our buildings allow for conversion to more energy-conscious use later. It costs us more now, but might earn us more later on."

Whilst embracing a contingency approach to remove air-conditioning, the potential of other varieties of MM do not seem to have been appreciated (or perhaps they were, and rejected).

D2.3.2 In another recent paper [76], developers MEPC say that energy efficient practices can only be given high priority if they increase letting potential or reduce capital cost. They see opportunities for openable windows and a relaxed atmosphere on a green field site, but not in a city dealing operation; and for energy-efficiency in some pre-lets and shell-and cores, but not in fully-fitted buildings. They note the supply-side conspiracy of letting agents, funders, and developers (aided and abetted by design engineers!) to produce complex and sophisticated buildings, which are then poorly-commissioned and rarely-understood by their occupants and maintenance staff, leading inevitably to higher energy consumption than their predecessors. However, they note that tenants now wise to this are beginning to demand simpler systems over which they have adequate control. They see change coming from tenant pressure; increases in the price of energy; inclusive leases with developers responsible for running costs; regulations; commonly-agreed voluntary benchmarking standards; and less conservatism by engineers in efforts to improve efficiency without adding cost or complexity. Of these they regard tighter legislation as the best bet: demands from occupiers might also do the trick but not, they think, at today's low fuel prices. In our view MM might square the circle, but only if developed not to become yet another way of introducing unmanageable complexity!

D2.4 A RECENT TEST

To our knowledge, British Gas Properties is the only developer to have completed three significant MM buildings: a small one at Loughborough (which has been occupied for about two years - a second phase is now under construction); a larger one at Leeds, completed at the end of 1995 but not yet let; and a third just completed at Reading. This last was to have been pre-let to British Gas, but is now surplus to their requirements. However, the developers says that their experience in dealing with them as prospective tenants has increased their understanding of the potential and pitfalls of the MM approach, and we hope we may be able to discuss this with them in more detail. At Loughborough we understand there were some initial problems because the tenants were unfamiliar with the systems and had not been operating them as the designers had intended, and there may be lessons to be learned. At Leeds, there was considerable market research into the views of potential tenants: who reportedly did not initially understand the concepts, but warmed to them once they were explained. Since completion, prospective tenants are reported to have been enthusiastic about the building and its low-energy features - though it has not yet been let.

D2.5 THE NEED FOR BETTER UNDERSTANDING

In spite of the considerable and growing interest in MM, it does seem that its principles and potential are not yet fully understood or exploited: they need more careful exploration and explanation. For the speculative market - at present the most cautious - it could perhaps offer the greatest potential returns: the flexibility offered by AC buildings is often illusory (at least at reasonable cost), though the prospect may be sufficient to clinch the deal! On the other hand, problems that this study has begun to reveal suggests that there may be some foundation for the caution about MM - both by the developer and by the tenant, although in the buildings surveyed to date the problems appear more likely to surface in the form of high energy use rather than than lower-than-average occupant comfort. More time, care and thought is required before good industry standards emerge. The proposed CIBSE Applications Manual could be a useful part of this process.

D2.6 MARKET POSITIONING

MM’s market positioning may also be wrong: most people - including building professionals - often see it occupying a rater foggy middle ground between NV and full AC, while in fact it could - and indeed seems to be becoming - mainstream. In marketability terms too, MM could often be seen and promoted as superior to NV or AC, and offering the best of both. Potentially this could reward all parties:

- the developer, with a more profitable and more widely marketable building;
- the tenant, with a more robust, adaptable, cost-effective building;
- the investor, with a better long-term capital asset, better able to meet changing and uncertain requirements;
- the occupant, with a better internal environment; and
- society, with longer-lived buildings with reduced environmental impacts.

D2.7 PROVISIONAL CONCLUSIONS ON MARKETABILITY

The traditional pattern of uptake of new technologies tends to be an S-curve, with typically some 50 years from initiation to complete acceptance - particularly where social and attitudinal change is also required. First the innovators, then the pioneers, then more rapid growth in the market, followed by reinforcement as standards are agreed and the industries and institutions who at first questioned and opposed the innovation begin to climb on board and reinforce the trend. MM concepts, spawned by the energy crisis in the early 1970s are now some 20 years old and beginning to enter the rapid growth phase. However, they are still somewhat diffuse, and need focusing. It would also be worth asking developers, managers, owners and occupiers of mixed-mode buildings whether they would have the same again another time.

D3 Cost-effectiveness

D3.1 CONSTRUCTION COST LEVELS

While traditionally NV buildings have been considerably cheaper than AC ones, the difference is partly a consequence of building type, rather than the AC itself. In many MM buildings, the occupier wants all the attributes of AC - raised floors and so on, but without full AC - so the cost gap is much narrower. Designers and developers may also want to deliver a similar external appearance too (viz: the attractiveness of glassy curtain walls in some recent MM buildings), even though this will tend to increase summertime temperatures and require complex mitigation systems. In addition, the spatial efficiency of MM may be lower, both in terms of the amount of floorspace that can be put on the site [36] and in the efficiency with which that space can be used. For example, access to windows requires space, and may also restrict furniture layouts. While there may be some savings in plant space, its location is often not very suitable for other purposes; and past experience suggests that squeezing floor-to-floor heights in non-AC buildings is not a good idea.

D3.2 DATA FROM COST MODELS: BUILDING SERVICES COSTS

Air-conditioned offices today cost typically in the region of £ 1000/m^2 gross and naturally-ventilated some £ 150/m^2 less. However, the range of individual figures for each type is wide with budget levels for “prestige” buildings being nearly twice as much as for low-cost offices for letting [97]. Cost models recently-published [77, 78] give typical M&E services subcontract costs of £ 278/m^2 for speculative commercial urban offices with fan-coil air-conditioning and £ 125/m^2 for an out-of-town naturally-ventilated office with perimeter heating: the mechanical services elements were £ 143 and £ 32 respectively. The figures exclude main contractor’s profits, attendance, builders work, and contingencies, which would add perhaps 20% to the M&E figures. Although including a basic fit-out, prestige developments and tenant requirements would add to these costs. Indeed, a more recent paper [96] gives ranges of £ 150-175 for plant, £ 90-100 for distribution and £ 200-250 for fitout. Services for MM buildings would be expected to fall somewhere in the middle of this range. For example, [96] indicates elemental costs of £ 135/m^2 for heating and displacement ventilation (a common choice for today’s MM offices) versus £ 210 for VAV air conditioning.

D3.3 BUILDING FABRIC COSTS

Whether the fabric of a MM building costs more is a moot point: although openable windows with solar control devices etc will tend to be added-cost items, in practice the slick, sealed facades of many AC buildings are not cheap and the differences may be small or even negative. For example, in [85] a Dutch developer noted the market was prepare to spend large sums on curtain walling, take on an expensive commitment of having to clean it 4 to 6 times a year, and ending up with the most expensive construction in both capital and maintenance terms, together with the highest cooling loads (or summertime temperatures)! Similar conclusions were reached by Davis Langdon Consultancy in support of the EnREI Passive Solar and Air-Conditioning study [83]: while good, well-controlled windows naturally cost more (though some styles -for example aluminium-clad timber can be highly competitive), well-designed facades need not in relation to market norms for good-quality AC buildings.

D3.4 DATA ON RECENT MM OFFICES

At a recent conference [35], the engineer of British Gas's MM building in Reading stated that the savings in capital and energy costs between this and an AC office were only about £100 - 150 and £ 2-3 per square metre respectively. At Ionica, the QS [53] identified a saving of £ 70/m^2 (or about 6%) in relation to a traditional air-conditioned building; and Ionica is all-electric, which would tend to have made it slightly cheaper in any event. The cost comment AJ article on Addison Wesley Longmans [91] states costs 5% below the norm, although reduced servicing costs had been compensated by higher envelope costs, including cladding, sunscreens and 1.2% for thermal mass on the upper floors (concrete roof with garden rather than the normal lightweight steel construction). At Leeds City Office Park the architect stated [86] that openable windows had added about 13% to the total cost of cladding and sunscreens. All these figures seem to confirm typical capital cost savings per square metre of some 5% (for a fully mechanically-ventilated solution) to 15% (for a contingency design) in relation to air-conditioned buildings of similar perceived quality standards.

D3.5 DESIGN COSTS

Reference [76] asks for much more up-front design, and states that it is arguably more difficult to design a simple building than a complex one (or should it be a complicated one?). This is confirmed by the architect of the Power Gen building who is reported [53] as saying that a "low-effort" (for the occupier) building probably needed twice as much design effort as a standard speculative office block - though we imagine that this effort was as much in the quality of the team and of the thinking as in raw time spent.

D3.6 PROVISIONAL CONCLUSIONS ON COSTS

MM designs will normally be a little cheaper than AC buildings of a similar quality standard, although they can be more expensive than basic AC buildings. While they may be (and have been) attractive to owner-occupiers, the public sector, and as pre-lets, in the speculative market they could be bad investment value unless they command greater, or at least similar, rentals to AC buildings. Alternatively developers and investors with a longer-term view can regard MM design as an insurance premium which is likely to reduce future risks of obsolescence and unlettability or increase the prospect of higher future rental income and/or capital value. However, work will need doing on both increasing the perceived and actual value of this approach and on developing more adaptable, robust and cost-effective solutions - for example using *contingency* design principles.

D4 Energy and environmental benefits

D4.1 INTRODUCTION

MM designs offer the prospect of lower energy consumption, costs and greenhouse gas and pollutant emissions than AC ones, simply because their HVAC systems should be lower-powered and on less. The MM buildings chosen for the EEO/BRECSU Office Case Studies certainly confirmed this for the normal services of HVAC and lighting (though in several, special areas such computer rooms and restaurants necessarily added to total consumption), as illustrated in the comparison graphs of energy consumption, energy costs and carbon dioxide emissions in Reference [2]. While the VAV air-conditioned *One Bridewell Street* [79] performed equally well, it was very much the exception - particularly in its quality of management - and in subsequent studies over the last six years WBA has still not found a fully air-conditioned building which matches it.

D4.2 WHERE MIGHT THE SAVINGS COME FROM?

The main energy savings would be expected to be for fans and cooling. In highly-insulated trickle-charged buildings with high-efficiency heat recovery systems there is also a prospect of savings in heating: though in terms of cost and carbon dioxide emissions electricity tends to be the more important item. In monitored buildings in the UK to date, any predicted CO_2 savings from added mechanical ventilation and heat recovery have frequently evaporated once the extra energy consumption and CO_2 emissions associated with the fans and other parasitic losses have been taken into account. There are several reasons: more ventilation than natural; the need for preheat on cold mornings (even sometimes in warm weather); parasitic losses (in particular the fan electricity consumption with its high cost and CO_2 overhead) and the high risks of un-noticed wastage. However, the potential is definitely there.

D4.3 ASSOCIATED EFFECTS

In more “natural” environments with openable windows, one also often finds lower lighting energy use than in sealed air-conditioned buildings. While the reasons for this are complex, (for example AC buildings tend to have deeper plans and more intensive occupancy) it does appear that the better outside awareness provided by openable windows can encourage people to make less use of the lights.

D4.4 ENERGY DATA FROM EXISTING MM BUILDINGS

Figures D4.1 and D4.2 put together the information we have to hand on annual energy consumption (see tables B1 and B2) and associated CO_2 emissions. They include data from twenty-four MM buildings: all offices except for *Solid State Logic* (office/light industrial), *Constable Terrace* (student residential - with consequently a high domestic hot water consumption), and *Elizabeth Fry* (university teaching). The information comes from disparate sources - some quite old - including BRECSU/EEMD case studies, buildings considered and rejected for these case studies, EnREI studies, PROBE surveys, articles in Building Services - the CIBSE Journal, and WBA’s private communications. The measurement conventions are not entirely consistent: for example the classification of end-uses varies, and some data is for building or HVAC services only. While for the majority of the buildings the floor area denominator is treated area, for other it may be gross area - which is typically 5-15% greater and will falsely reduce the energy consumption indices.

D4.5 COMPARING THE DATA

As revealed in the EEO/BRECSU office case studies [2], energy consumption indices fall into a wide range which depends partly on what is happening in the building. In particular, buildings with a high proportion of cellular offices and individual rooms tend to use less energy because the environment is more “domestic”, passive measures are more readily usable, and the occupant is more in control. Conversely, in more open and deep-planned spaces, more management is required, it becomes much more difficult to determine what individuals really need, and systems tend to default to ON. In addition, the larger buildings tend to contain special areas with more intensive energy use, for example restaurants, computer and communications rooms.

FIGURE D4.1 Annual delivered energy consumption by mixed mode buildings (kWh/m2)

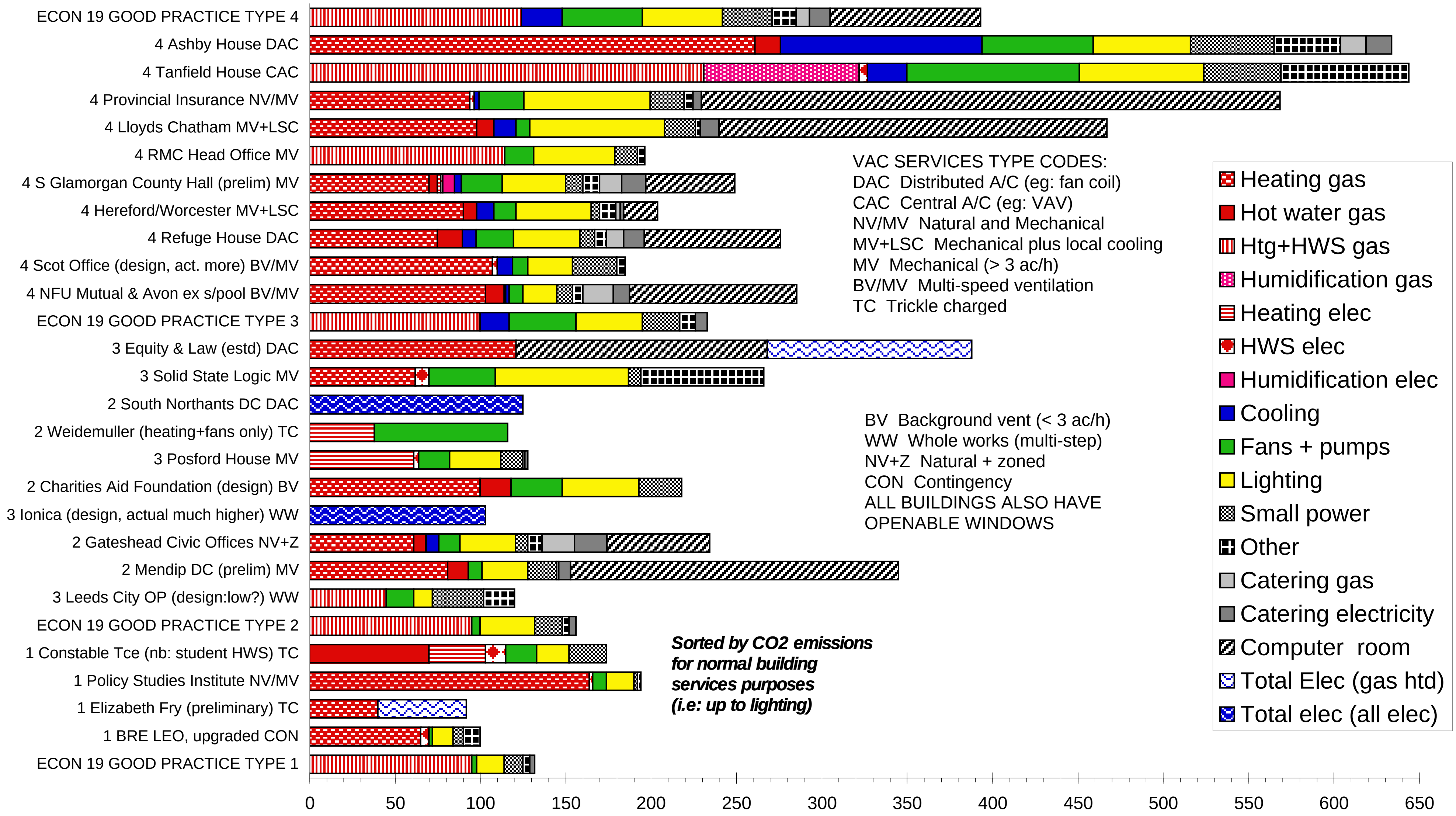
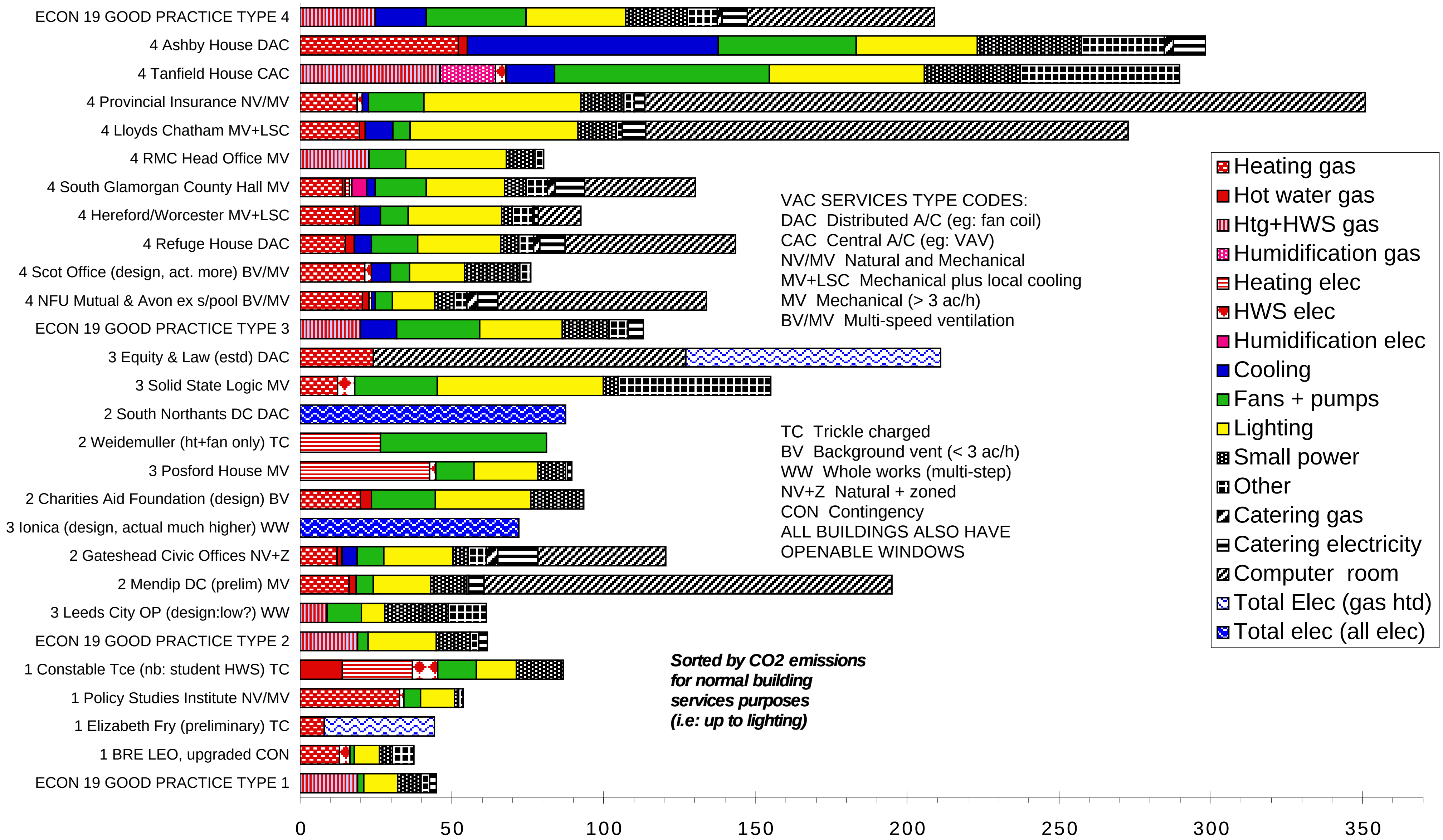


FIGURE D4.2 Annual carbon dioxide emissions from mixed mode buildings (kg/m2)



- *Policy Studies Institute* is disappointing on the heating side. This was pointed out in the EEO case study [18], and is related to poor control and in particular to refurbishing its elderly and oversized cast-iron boilers, and converting them from gas to oil, rather than replacing them with newer technology.
- Even after allowing for its high hot water consumption (which arises from a combination of use patterns, inefficient generation, and insufficient water conservation measures), *Constable Terrace* just fails to make the grade. The reason is that more (electric) heating was used than expected, owing to additional window opening (partly because of smells recirculated by the mechanical ventilation system) and the need for boosting during partial occupancy in vacations when there was less heat to recover than anticipated. It is difficult to achieve emissions targets with electrically-heated buildings in the UK because of the high CO_2 overhead of electricity generation. *Designers and their clients and advisers should be cautious when importing techniques and technologies from other countries where a high proportion of renewable and/or nuclear energy is used to generate their electricity, and where natural gas is not readily available as a competitive and relatively clean heating fuel.*

D4.10 WHAT HAS BEEN ACHIEVED IN TYPE 2/3 BUILDINGS?

Carbon dioxide emissions at *Weidemuller* (with very high fan energy consumption) *Solid State Logic* (with high lighting and fan energy consumption) and *Equity and Law* (insufficient information but probably high), and we understand *Ionica* exceed the Type 3 GP benchmark. Others do much better, with *Mendip* and *Gateshead* around or just below the Type 2 GP benchmark. While *Charities Aid Foundation* and *Posford House* lie just below the Type 3 GP benchmark, this is somewhat disappointing because they appear to have planning and occupancy characteristics more similar to Type 2 buildings. Perhaps they could have pursued a contingency or trickle-charged route.

D4.11 WHAT HAS BEEN ACHIEVED IN TYPE 4 BUILDINGS?

Many of the Type 4 buildings have achieved the ambition to provide a Head Office environment with similar or lower emission levels than Good Practice for a standard Type 3 air-conditioned office - which in itself we have found that very few air-conditioned offices achieve. In particular:

- There is a tight cluster: *RMC, South Glamorgan, Hereford/Worcester and Refuge* with very similar levels of emissions (typically 67 kg/m^2 - up to the top of the lighting bar: 23% and 37% respectively below the relevant parts of the Types 3 and 4 GP benchmarks. Perhaps this should be a new standard? However, in all these buildings lighting energy consumption (average 42 kWh/m^2) is high: with today's technology performance in the 20 - 30 kWh/m^2 region should be attainable in this type of building.
- *NFU* [58] is unusually low in its consumption and emissions. There seem to be three main reasons for this:
  - A two-speed ventilation system which during the day is normally operated *concurrently* at low speed, giving large savings in fan energy consumption.
  - Reasonably well-controlled daylight, low design illuminance levels , and relatively good (for its time) central and local lighting controls.
  - Practical facilities management experience which abandoned mechanical night ventilation in favour of natural ventilation through the relatively secure high-level hopper windows. MFP's EnREI studies [8] found this to be effective. This parallels BSRIA's findings [105] on Durrington Bridge House.
- *Lloyds Chatham* and *Provincial Insurance* have higher consumption, but only for lighting. These schemes date from the 1970s and have not benefited from today's more efficient technology and lower illuminance standards.
- Design targets for the *Scottish Office* were somewhat higher than the measured levels at *NFU,* largely owing to the inclusion of refrigeration to meet higher estimated internal gain levels. However, early operating experience suggests that the targets may have been optimistic.
- In spite of claims, *Ashby House and Tanfield House* essentially perform as typical air-conditioned head offices and no energy benefits from the MM approach are discernible.

D4.12 ENERGY USE FOR HUMIDITY CONTROL

When ECON 19 was being prepared, most AC offices had abandoned humidification owing to the legionnaires' disease scare, and so its energy use was not included in the benchmarks. It is now creeping back, particularly with VDU legislation and the increasing use of full-fresh-air systems. Of the buildings included, only *South Glamorgan* and *Tanfield House* have humidification: packaged electric steam and central gas-fired steam respectively. Energy consumption by humidification is very variable depending on the standards adopted: at *Tanfield* a minimum level of 45% RH was expensively maintained with a gas consumption of 90 kWh/m^2. *South Glamorgan* used it only in cold, dry weather with an estimated electricity consumption of 5 kWh/m^2 (or a CO_2 equivalent of about 17 kWh/m^2 of gas). However this electricity was probably very expensive as it would would have been likely to have added to the wintertime maximum demand charges. Some recent studies suggest that added moisture often creates as many problems as it resolves, at least until RHs fall below 25-30%: and in cold climates wintertime RHs very much lower than this are routinely accepted. *Advice on appropriate levels, provision and operation of humidification would be desirable.*

D4.13 ENERGY CONSUMPTION BY FANS

Perhaps the key to energy efficient design of MM buildings is to minimise the energy use by the fans. This is the product of four numbers:

1 The design air change rate, or rates, in ac/h or l/sec per m^2. For a typical ceiling height in recent MM buildings of some 3 metres (including the volume of air in coffers etc.), 1 ac/h is equivalent to 1.2 l/s per m^2.

2 The specific fan power (for supply and extract combined). For ducted mechanical ventilation and air-conditioning, this typically falls in the range 1 to 4 Watts per l/sec. Unducted systems, and multi-speed ducted systems operating at low speed, can use less than this.

3 The hours of use of the system. This can range from a few hundred hours a year for on-demand night ventilation, at *Durrington Bridge House* and *York University's Computer Science Laboratory*, to 8760 hours per year on continuously-operating trickle-charged systems such as Termodeck at *Weidemuller* and *Elizabeth Fry*.

4 The proportion of the total floor area which has mechanical ventilation.

D4.14 A GEOMETRIC PROGRESSION

In good MM design, one should aim to keep all four numbers above low, as the multiplier effect - for both good and ill - can be tremendous. As a general rule, the higher the air change rate, and the more sophisticated the system, space restrictions, noise attenuation and air resistance through added features such as heat recovery devices increased the specific fan power. In addition, the higher the air change rate the more people are likely to notice the difference between the system operating or not, which may reinforce the tendency to default to ON. There may also be technical problems which reinforce this.

For example, one building WBA visited had a mechanical air change rate of 6 ac/h at a specific fan power of 4 Watts per l/sec, giving an installed fan power of 28.8 W/m^2. For various reasons, including the sensitivity of the plants in the atrium to solar gains at weekends, this system defaulted to ON and ran continuously, giving a massive annual energy consumption of 250 kWh/m^2 of office area (or some 170 kWh/m^2 of treated area) with some additional consumption from boost extract ventilation to 10 ac/h in hot weather.

A more recent example is the trickle-charged *Weidemuller*. Here the continuously-running ventilation had a specific fan power of 3 W/l.s and chalked up an annual consumption of 78 kWh/m^2 [92]. Most of the cooling influence of this system was also devoted to counteracting fan gains and other forms of heat pick-up, rather than cooling the building! The *Elizabeth Fry Building* reportedly performs much better, though [92] quotes a specific fan power of 2 W/l.s, while the increasingly widely-accepted norm for an energy-efficient building is a maximum of 1 W/l.s. [28, 73, 104, 108]. Admittedly this can be difficult when there are a lot of filters, heat exchangers etc in the air stream, but an absolute maximum of 1.5 W/l.s is recommended. Values less than 1 W/l.s can be achieved on low-speed operation, as at *NFU*.

D4.15 CONCLUSIONS ON ENERGY AND ENVIRONMENTAL BENEFITS

While MM buildings can provide benefits, they require attention to detail in strategy, design and management and are often somewhat fragile. As a general rule, the good practice design principles set down in Section C2 need to be followed carefully. *The proposed CIBSE Applications Manual could illustrate in some detail the application of these and other principles to the design of different varieties of MM building.*

D4.16 AVOIDING WASTEFUL OPERATION

Designers, reasonably enough, tend to be optimistic about their proposals. However, recent studies emphasise the importance of minimising the downside risk of potentially good ideas. Without care and circumspection, these can very easily turn into "nuisance" features and technologies which can prove baffling or annoying to the occupant, difficult to understand and to manage, and to have unintended consequences - frequently for excessive energy use. Some of the problems regarding comfort and control have already been outlined in Section C5. Below we list some generic problems which often lead to energy wastage.

C4.17 COMMON CAUSES OF ENERGY WASTAGE

Many buildings suffer problems which tend to reduce performance and/or increase energy consumption - with systems either defaulting to "ON" when they could have been off (or at least at substantially reduced output), or operating inefficiently. The energy consequences of these tend to be most severe in the more sophisticated and highly-serviced buildings, which until recently have tended to be AC. However, the more complex MM buildings are at risk of similar afflictions. The root cause of the problems is often poor usability of complex systems, with the following generic causes:

i *The "tail-wags-the-dog" effect*, where whole systems are brought on to service small loads, for example a central chilled water system servicing a few 24-hour machine rooms (in one installation the energy used at night by the pumps *alone* was over five times the cooling load). The same thing may happen with central ventilation systems, as discussed in D4.14. Suitable local self-contained or supplementary systems should be used; or if the main systems are zoned the central plant needs to be designed and controlled so that it can operate efficiently at small fractions of its full load.

ii *Unwanted operation,* when systems run long hours or constantly because the controls have been over-ridden for some unusual purpose and not reset afterwards; or because automatic controls (eg: frost thermostats or hidden hardware or software interlocks) bring on systems unnecessarily owing to poor setting, calibration or programming; or as a result of changes whose repercussions have not been fully appreciated. Suitable fault detection should be incorporated, for example by reporting the running hours of devices and systems during periods when they are programmed to be off.

iii *Unintended operation,* when systems activate (or fail to de-activate) themselves when not required, often outside the occupied period. Anticipatory systems (eg: for optimum start, night cooling, or reservoir charging/discharging) are particularly prone to this. Ideally, hours should be logged and compared with heuristics of likely predicted requirements.

iv *"Embedded[4] " system malfunction,* where systems no longer improve performance or save energy, and may even increase it as a result of parasitic loads (see below). Examples include heat recovery systems which break down un-noticed (or continue to operate when cooling is required); "free" cooling and enthalpy control systems, which often introduce the wrong proportions of outside air; and unnecessary heating (through recirculation, letting-by or even deliberate heating) of air intended for night cooling (and sometimes during the day too). Ideally performance of such systems should be automatically monitored against the design intentions.

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4 The term "embedded system" is used to describe one which is installed to improve economy but which does not necessarily or immediately affect perceived performance.

v *Parasitic losses* are particularly common with embedded systems. For example extra fan power is required to drive air through heat exchangers; heat recovery from chillers usually reduces refrigeration efficiency and additional fan and pump power may be required for heat rejection and redistribution. These parasitic loads are nearly always electric - with a high cost and CO_2 emissions overhead - and can often be present whether or not heat is being recovered, hence eating into any improvements and savings. Designers should attempt to reduce these losses to a reasonable minimum and if possible to avoid them entirely when energy is not being transferred, for example by switching-off and/or by-passing the device concerned.

vi *Antagonistic losses* usually take the form of heat fighting cool, for example heat being recovered unnecessarily when systems are in free or mechanical cooling mode; simultaneous humidification and dehumidification; or (particularly common with MM systems) mechanical systems competing with air coming through the windows. System state and performance should be monitored and clash alarms reported.

D5 Health issues

D5.1 At this stage it is difficult to say much about health issues. People often say they feel healthier in NV buildings even though in theory MV and AC should provide better air quality. Recent studies have shown that there is some sense in this, and not only psychologically: mechanical systems can not only introduce, recirculate and distribute pollutants, but if poorly designed, cleaned and maintained they can harbour and generate pollutants of their own. There is also no mechanical equivalent of throwing open the windows for “shock” or “rapid” ventilation.

D5.2 On the other hand, some insidious air pollutants, such as radon, cannot be sensed. and well-designed mechanical systems can ventilate with greater effectiveness than natural ones, particularly in cold (or very hot) weather in which increased levels of natural ventilation would carry energy penalties. Potentially there seem to be health benefits in trickle-charged MM buildings in which a small amount of high quality mechanical ventilation can not only maintain minimum levels of air quality but help to achieve thermal stability and to remove localised pollutants at source.

D5.3 The intermittent operation of some mechanical systems might cause heath problems, in the same way that the greatest likelihood of legionnaires’ disease from cooling towers was on start-up after a long idle period when the bacteria had had a chance to multiply. Unused mechanical supply systems could potentially fester with dust, puddles, vermin etc. and spring into life distributing the remains about the building. Attention to hygiene in design, operation and maintenance is likely to be come increasingly important for all mechanical ventilation systems, in MM buildings and elsewhere.

D6 Conclusions on related issues

D6.1 Under all the four headings considered here, we have discovered areas of good prospects but somewhat uncertain knowledge and understanding. There is a clear need for further study, both on developing the ideas and on understanding the performance of existing MM buildings and the opportunities for and methods of improvement.

E NEXT STEPS

E1 Overview

E1.1 A SHORT HISTORY

This study has identified a wide variety of MM buildings. The first wave was designed for the private and public sectors as a response to the 1970s energy crisis. By the mid-1980s - and with a few notable exceptions - MM had been somewhat eclipsed by the rise in information technology and over-estimates of its likely heat gains, rising prosperity, falling fuel prices, and the institutional standard of VAV air-conditioning. However, in the 1990s concerns about the environment, value for money, no-frills adaptability and occupant health have created a surge in interest, and there are even a few speculative examples.

E1.2 ARE MIXED MODE BUILDINGS ACHIEVING THEIR OBJECTIVES?

We have identified three main objectives for all MM buildings. These are summarised below, together with comments on the extent to which we think they are being met.

1 *Longer-lived buildings which can be adapted to changing requirements, standards and priorities without wasteful over-provision or unnecessary costs.* As yet there is little evidence, except on capital costs, which for buildings already equipped with complementary mechanical ventilation are reported as typically 5% less than comparable air-conditioned buildings, sometimes rising to as much as 15%, particularly for *contingency* designs with few mechanical ventilation and cooling services.

2 *Better occupant satisfaction by combining the perceived advantages of openable windows with any mechanical servicing necessary.* There is some indication that people are more tolerant of environmental conditions where they can open the windows. However, occupant questionnaire surveys in recently-completed buildings with advanced natural ventilation indicate that all is not well, and that what tolerance there is accrues primarily to those who are near and in direct control of the windows. In general, MM buildings seem to do considerably better. However, the samples are not yet large enough to be statistically significant. We have also found that good managements tend to procure better buildings and manage them and their staff better, so there may well also be knock-on effects.

3 *Reductions in energy use and associated emissions by avoiding the unnecessary operation of mechanical systems at times and in places where natural ventilation could meet the requirements more effectively.* Although there are some successes, meeting this requirement without approaching the energy consumption levels of comparable air-conditioned buildings is proving to be more difficult. In practice many ventilation systems are oversized, not very efficient, and operate for more hours under worse control than the designers had predicted, bringing additional running costs and extra heating, cooling and particularly fan electricity consumption. While poor management is often blamed for this, we think the reasons are much more deep-seated.

E1.3 WHAT IS GOING WRONG?

As yet there seems to be insufficient understanding of the following major issues:

i *How to achieve adaptability cost-effectively.* Many buildings appear to be over-serviced and insufficiently adaptable. Sometimes moneys might have been better spent on reducing unnecessary heat gains than on providing ventilation plant to mitigate them.

ii *How occupants and management really behave.* In hindsight, design expectations of occupiers often seem to have been unrealistic. Better briefing and consultation is not the complete answer to this: client and designer can unwittingly connive in creating false expectations. There is no substitute for monitored pilot projects, plus post-occupancy surveys to improve industry awareness generally.

iii *What can go wrong with systems which are supposed to be energy-efficient.* This ranges from basic efficiency (in many MM buildings the specific fan power is far too high) to more rigorous analysis of possible failure modes and their implications.

iv *Appropriate design of controls,* which work well and are effectively usable by occupants and management.

E2 What needs doing next?

E2.1 MORE INFORMATION

While this report has established a framework for thinking about MM buildings, it is short on information and exemplars. In terms of information, we think it would be very useful to undertake rapid building appraisals with energy, occupancy, and management surveys on a number of more recently-completed MM buildings. In the first place these could be along the lines of the current series of PROBE studies for *Building Services - the CIBSE Journal*. Follow-up monitoring might be required in a few cases.

E2.2 BUILDINGS TO SURVEY

Many in Table B2 would be of interest, and in particular:

- BSI Chiswick: a refurbished tower block with interlocked fanlights and fan coils.
- * Elizabeth Fry Building, University of East Anglia. One of the first trickle-charged buildings which appear to be fulfilling its promise.
- DTI refurbishment, Westminster. A rather elaborate MM strategy: how well is it working in practice for occupants, management and energy?
- IBM Software Laboratory, Hursley Park. Another building with interlocked fan coils. Energy may be difficult to measure because the building - on a large site - might well not be sub-metered.
- Inland Revenue, Durrington Bridge House. What seems to be a fairly straightforward atrium building which BSRIA said could possibly be even simpler. Can it?
- Inland Revenue, East Kilbride. An interesting form with a number of variations. Do these affect occupant perceptions?
- John Menzies, Edinburgh. A good-looking but relatively simple design. But have too many of the frills been removed?
- * Marston Books, Milton Park, Abingdon. A simple *contingency* design. Some other contingency designs have done as well as the mechanically-ventilated examples without the cost, complexity and energy consumption of the mechanical systems. Will this?
- Powergen, Coventry. A potentially interesting, relatively simple design, and one which reportedly did not need its chillers to operate last summer.

We understand that some monitoring is already occurring (or is about to occur) in the asterisked buildings, but this may need to be enhanced. Information from other monitored buildings, in particular *Inland Revenue Nottingham* and *Ionica* should also be included.

E2.3 BETTER EXEMPLARS

A study is recommended of the potential for MM design, both reviewing past exemplars and current ideas and looking at generic possibilities for the future. It should include ideas for *contingency* building shells and for the “drop-in” services which might be added to them. It should also consider trickle-charged designs and methods of increasing their capacity to deal with additional heat gains and ventilation requirements quickly, easily and if possible reversibly. Its report would be developed into a well-illustrated publication which would help to raise awareness of the potential whilst identifying the process and the pitfalls.

E2.4 A MARKET SURVEY

This would include expectations of and attitudes to MM buildings, both of those who have ben concerned with them as procurers, designers, occupiers, commissioning engineers, managers and letting agents, and of the wider community.

E2.5 EXPLORATION OF CRITICAL FEATURES AND DETAILS

Certain aspects, and in particular windows, controls and control interfaces, are critical to the success of many MM buildings. A detailed study is suggested of the best means of achieving critical goals, for example effective low-energy night ventilation.

E3 The CIBSE Applications Manual

E3.1 In this report we have identified - directly and indirectly - more than enough material for a CIBSE Applications Manual, and many reasons why such a manual could be valuable. We think it would be helpful to start drafting this as quickly as possible - by doing so (and by reviewing it) we think that the gaps in the arguments would become most rapidly apparent. These could then be used to direct any further research and investigation beyond that outlined in Section E2.

THIS SECTION WILL BE EXPANDED FOLLOWING DISCUSSIONS WITH THE PROJECT OFFICER AND THE ADVISORY GROUP.

Appendices

APPENDIX X
A REVIEW OF MIXED MODE DEFINITIONS

X1 INTRODUCTION

X1.1 This appendix includes some arguments which underlie the discussion on definitions in Chapter A2 of the main report. The Max Fordham & Partners' (MFP) definitions: *contingency, concurrent, changeover* and *zoned*, [3] are repeated for convenience, other definitions introduced, and some conclusions drawn.

X2 THE MFP DEFINITIONS

X2.1 *CONTINGENCY* designs are ones in which mechanical systems can easily be added (or removed) if this proves necessary. At one end of the scale comes naturally-ventilated buildings or spaces (designed for example along the lines discussed in the CIBSE Applications Manual [1]), which have a clear contingency plan (or plans) for adding mechanical ventilation and/or cooling if required. At the opposite end, a sealed air-conditioned building may be designed with the potential to revert to a less energy-dependent form of operation, for example if it is planned for natural ventilation (and having suitable openable windows etc. - even if initially they are locked shut), or for some form of *concurrent* or *changeover* operation (see below).

X2.2 *CONCURRENT* is the most common form of hybrid, where mechanical ventilation - with or without cooling - operates in parallel with openable windows. Normally the mechanical system suffices, controlling draughts and air quality and removing heat, but people can open the windows if they want to. The systems must be complementary, not antagonistic. Site studies however suggest that mechanical systems are often too powerful, not very efficient, and run much more than necessary and than the designers anticipated.

X2.3 *CHANGEOVER:* Natural and mechanical systems are available and used as alternatives according to need, but do not normally operate at the same time. Some examples include:

- *Seasonal changeover,* for example with windows openable in mild weather but locked shut in winter, when mechanical ventilation is used to meet required air quality standards, avoid draughts and possibly save energy by using heat recovery.
- *Night cooling,* with natural ventilation during the day, and mechanical at night to remove excess heat built up in the fabric. This is useful where windows cannot be left open, or where air is passed over the structure to enhance heat storage effects.
- *Local changeover,* where window detectors switch off nearby air-conditioning or comfort cooling units when the window is opened.

In practice it can be difficult to implement changeover design intentions reliably (apart perhaps from *local)* owing to their complexity; an absence of input information to make an informed choice; poor or non-intuitive user interfaces; or adverse occupant reactions to systems which change their operating mode capriciously (at least to them). Consequently changeover systems often default to *concurrent* operation, nearly always with increased energy consumption and sometimes with worse performance - at least in engineering terms.

X2.4 *ZONED, with different services in different parts of the building:* for example comfort cooling locally for hot spots (probably a special case of *contingency* design), or in parts of the building (say) with a deeper plan, high solar gains, or limited opportunities for natural ventilation. However, such variations in the servicing of nearby and operationally similar spaces in the same building can cause problems for users - either through jealousies or because the different systems require different user behaviour: careful study and guidance is essential. Another variety of zoning is where services in special areas (eg: restaurants, computer suites, meeting rooms, swimming pools and toilets) differ from those in other parts of the building - but since this is perfectly normal it may not be helpful to classify this as MM.

X3 SOME OTHER DEFINITIONS

X3.1 CIBSE NATURAL VENTILATION APPLICATIONS MANUAL [1]
This quotes the MFP definitions, but also mentions *seasonal mixed mode*.

COMMENT: We consider that *seasonal* can be regarded as a special case of *changeover,* and in general terms a changeover can occur for any reason.

X3.2 D ARNOLD [2]
This states that MM is a strategy which attempts to combine the best features of both natural ventilation and air conditioning, in holistic designs which treat building and services equally, using different features of the systems at different times of the day and the year. For most of the year, MM is seen as operating in natural ventilation mode, perhaps with mechanical ventilation coming on if air quality deteriorates or the temperature gets too high. Once the natural systems became inadequate to restrict the rise in temperature during the day, mechanical systems would provide “just enough” cooling - by free cooling, mechanical refrigeration, or night cooling and fabric thermal storage. Suitable trade-offs are discussed in the paper.

COMMENT: We regard this as a restrictive definition, although the paper identifies some useful objectives and procedures for certain *changeover* systems. While “just enough” is a useful and desirable principle, evidence from case studies suggests that in practice the changeover points are not always easy to identify, and that people can be inconvenienced by the changeover itself - when temperature, air movement and required user behaviour can alter for no apparent reason. Most managements therefore tend to run mechanical systems more liberally and concurrently than the designers ever anticipated.

X3.3 D BRAHAM [13]
This author chooses an even more restrictive definition, of openable windows for the daytime, mechanical underfloor ventilation for overnight cooling when necessary, and controlled ventilation with heat recovery in winter - again a variety of *changeover* system. He differentiates this from “passive heating and cooling”, a *concurrent* system which uses year-round mechanical ventilation with heat recovery, hollow core slabs, and openable windows. He also includes a *changeover* mode which has supplementary cooling in very hot weather.

COMMENT: We regard all three options as variations on two of the MM themes.

X3.4 BRECSU [8]
On page 18 this suggests that many mechanically-ventilated *concurrent* designs fall into the *contingency* category, because cooling coils could be fitted in the air-handling units, or sensible cooling could be added in the rooms to which some mechanical ventilation was also available.

COMMENT: While this is a reasonable interpretation, the original intention of MFP’s *contingency* definition was to indicate *buildings* with latent potential but not able to exploit it immediately, either because:

- there was no need, e.g: a building which could cope for the moment with natural ventilation
- there was no hardware *in situ;* for example in a naturally-ventilated building with space provision only for future mechanical systems; or
- it would be unsuitable (for example for a space which had openable windows but for the time being needed to be sealed and air-conditioned - perhaps to meet exacting environmental standards).

In response to the BRECSU point, we consider that all varieties of mixed-mode are to some extent *contingency* designs, because part of their main purpose is to be more easily adaptable to meet changing circumstances. This point will be incorporated in some general objectives, see Section X6.2.

X4 DISCUSSION OF THE DEFINITIONS

X4.1 GENERAL OBJECTIVES

We recommend that the definition of MM is kept broad, and not restricted as suggested by some authors in Section X3. However, more detailed functional and technical classifications will be helpful, as of course they are for all types of system. Whatever their classification, MM buildings can be seen as seeking to achieve some, and often all, of the following objectives:

1. *Longer-lived buildings which can be adapted to changing requirements, standards and priorities, and serviced to meet occupiers' real needs whilst avoiding wasteful over-provision, unnecessary capital and running costs, or burdens for management.*
2. *Better occupant satisfaction by combining the perceived advantages of openable windows with any mechanical servicing necessary to provide suitable levels of health, safety and comfort.*
3. *Reductions in energy use and the associated greenhouse gas and pollutant emissions through avoiding the unnecessary operation of mechanical systems at times and in places where natural ventilation could meet the requirements more efficiently.*

X4.2 RE-ASSESSMENT OF THE MFP DEFINITIONS

The MFP definitions are already in the public domain (for example in references [1], [3], [6], [8] and [14]), have proved useful, and work well despite some shortcomings. To change them too much could well confuse people: we think it would be better for them to evolve through interpretation, development, and practical application. Possible shortcomings requiring attention are discussed below.

- WHEN SHOULD A BUILDING RATE AS MM?
  In our view a true MM system should combine natural and mechanical servicing options in one and the same space. *For a building to be called MM, such an approach would be widespread. Where it is not, parts of the building can still be designed on MM principles.*
- THE FOUR MFP TERMS ARE NOT MUTUALLY EXCLUSIVE
  The review in Part B indicates that the four terms: *contingency*, *concurrent*, *changeover* and *zoned* do not in fact describe distinct choices, but classification facets, of which more than one may be present. *A multi-faceted classification is needed to take account of this*.
- AT WHAT SCALE SHOULD THE TERM *CONTINGENCY* APPLY?
  To the whole building (as MFP originally intended), to some zones only, or to small-scale system modifications as suggested by BRECSU - like the added cooling coil in an existing AHU? *We prefer the original definition, possibly taken down to the zone. With the general objectives in X 4.1, a fine-tuning capability (like the added coil) is fundamental to the whole idea of MM.*
- WHAT ABOUT CONTINGENCY TO REMOVE PLANT?
  Is a strategy to remove mechanical systems (like the AC at Salford) different from one to add them (as at Body Shop)? *Not really, but this needs more consideration, both on grounds of marketability and perhaps to avoid a possible back-door route to full air-conditioning.*
- SHOULD ONE DIFFERENTIATE BETWEEN *CONCURRENT* & *CHANGEOVER?*
  This distinction seems to be more real to designers than in practice. The systems available in a building tend to be operated in the manner that management and occupants finds most convenient or reliable, and which leads to fewest problems and complaints[5]. *The key feature of both* concurrent *and* changeover *is that natural and mechanical systems are both present at the same time and are* complementary *in operation. Whether they are operated at the same time, as alternatives, or at all, is ultimately a management choice. We suggest that the distinction is retained, but to describe operating modes rather than as a fundamental element of building or system classification.*
- DO WE NEED EXTRA TERMS TO DESCRIBE ENGINEERING OPTIONS?
  This might include concepts such as perhaps *upgradeable* (say for the cooling coil) and *modular* (where additional units such as fan-coils can be easily added). *It is not yet clear whether this would be helpful.*

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3 Occupant surveys by BUS suggest that in group situations the situation of least complaint is not necessarily optimal. It is often that of least change and may even border on the threshold of discomfort.

X5 PROPOSED CLASSIFICATION FACETS

X5.1 We think that one can classify MM using four separate facets, each with two choices, as outlined below. In naming them here, words from MFP's definitions have deliberately been avoided for the time being.

X5.2 FACET 1 *WHOLE or PART?*
This facet relates closely to MFP's *zoned* classification. However, buildings containing differently-serviced zones but not designed with the potential for ready interchangeability or parallel running would not strictly count as MM.
Alternatively, one could omit this facet and instead apply the classification not to the building as a whole, but only to those parts of it which claimed to be MM.

X5.3 FACET 2 *ACTUALLY or POTENTIALLY?*
This is MFP's *contingency* classification, which may be applied to the whole building or to individual areas (but see point 1 above).
Explicit recognition of such latent potential is particularly important at the point of sale. If the thought and investment devoted to the contingency strategy is not valued by the market (be it customer or investor), nobody (except the odd enthusiast) will have the incentive to do it. The potential to alter or upgrade systems and subsystems is covered by the general attribute of adaptability, and does not appear to be essential to this aspect of the classification. However, this will be reviewed later.

X5.4 FACET 3 *COMPLEMENTARY or MUTUALLY EXCLUSIVE?*
If *complementary*, natural and mechanical systems are both physically present and operationally available, subject to management, control system or user choice (see point 4 below). In the *mutually exclusive* option, the choice of one system or the other stands until there is good reason for change - for example a major alteration in occupancy or equipment levels; and the change might well require some physical alterations.
We think that this facet can probably be discarded, with mutually exclusive treated as either:
- *a special case of* zoning *or* contingency *planning; or*
- *where natural and mechanical systems are both present, but the choice between the two is a long term-one, it could be regarded as an extreme case of* changeover*, in which the changeover option was seldom exercised.*

X5.5 FACET 4 *IN PARALLEL OR ALTERNATELY?*
This is the last facet because it is a matter of operational choice. *Parallel* is similar to MFP's *concurrent* option, and *alternate* to MFP's *changeover* option and to Reference [1]'s *seasonal* definition. *This is a useful distinction but should not be a primary means of classification. However, an understanding of these choices, and the related opportunities and pitfalls, is essential to the engineering of systems in which natural and mechanical systems are effectively and economically combined.*

X5.6 A FULL DEFINITION
A full definition, which takes account the four proposed classification facets, could be:
Mixed-mode is an approach to ventilating and cooling in which natural ventilation (normally using openable windows) and mechanical ventilation and/or cooling and air-conditioning systems are deliberately combined:
1 *For the* whole building *or for* parts *of it.*
2 Actually *(with both systems present) or* potentially *(in a building designed for easy addition, removal or alteration of part or all of the mechanical systems).*
3 *As* complementary *or* mutually exclusive *alternatives.*
4 *If complementary, by operating* in parallel *or* alternately**.**

X6 CONCLUSIONS ON DEFINITIONS

X6.1 USE OF THE TERM 'MIXED MODE'

Although more restrictive definitions have been proposed, we recommend that the term 'Mixed Mode' is used to describe the full range of combinations of natural and mechanical systems. Recommended general objectives for such buildings and systems are as follows:

1 *Longer-lived buildings which can be adapted to changing requirements, standards and priorities, and serviced to meet occupiers' real needs whilst avoiding wasteful over-provision or unnecessary capital and running costs.*

2 *Better occupant satisfaction by combining the perceived advantages of openable windows with any mechanical servicing necessary to provide suitable levels of health, safety and comfort.*

3 *Lower energy use and the associated greenhouse gas and pollutant emissions through avoiding the unnecessary provision and operation of mechanical systems at times and in places where natural ventilation could achieve the task more efficiently.*

X6.2 DIFFERENT CLASSIFICATIONS

The MFP classification: *Zoned, Contingency, Concurrent* and *Changeover* has worked well, but some shortcomings have been exposed. A classification system with four separate facets would be theoretically more appropriate, but rather than changing everything we recommend using the insight this brings to make minor alterations to the MFP definitions. A more elaborate classification does not seem worthwhile: more information would be imparted by adding specific technical details.

X6.3 RELATIONSHIP TO THE MFP CLASSIFICATION

The faceted classification makes four choices:

1 *Whole or Part?* MFP's *zoned* term can be retained to describe buildings which contain a variety of natural and mechanical systems. However, to be termed a MM *system*, natural and mechanical systems must be combined in the same space.

2 *Actually or potentially?* MFP's *Contingency* term can be retained for strategic options. Tactical options (such as adding a cooling coil) are covered by Objective 1.

3 *Complementary or Mutually Exclusive?* We recommend using the term *Complementary* to describe all situations where natural and mechanical systems are available together in the same space. *Mutually exclusive* can be considered as an extreme case of a *Changeover* operating strategy. However, the distinction can be useful in making strategic choices, see Section A3.1 of the main report.

4 *In parallel or alternately?* For *complementary* systems, MFP's *concurrent* and *changeover* are just two of a variety of possible and frequently interchangeable alternative operating strategies. Although one could attempt to classify the whole range of options in general terms, we do not think that this would be helpful. Instead, we think it would be better to ensure that the specific strategy or alternatives were set down clearly for the building or space concerned.

Some people already limit the term *mixed mode* to describing *complementary* situations, but we regard this as too restrictive because it excludes *zoned* and *contingency* options.

X6.4 RECOMMENDED SIMPLE CLASSIFICATION

Strategically, we suggest the options of *zoned, contingency and complementary*. Operating modes for *complementary* systems can then be broadly classified as either:

- *Concurrent,* where openable windows and mechanical systems operate together.
- *Changeover,* where the systems may operate in rapid succession but not normally together, except by default.
- *Alternate,* where a choice, once made (say to close the windows and operate full air-conditioning with humidity control) persists for a long time.

More detailed descriptions can then be provided as appropriate, for example say seasonal changeover with controlled mechanical ventilation in winter, mechanical ventilation with night and comfort cooling in hot weather, and openable windows at other times. However, as a shorthand, the original MFP 4-way classification may still be used.

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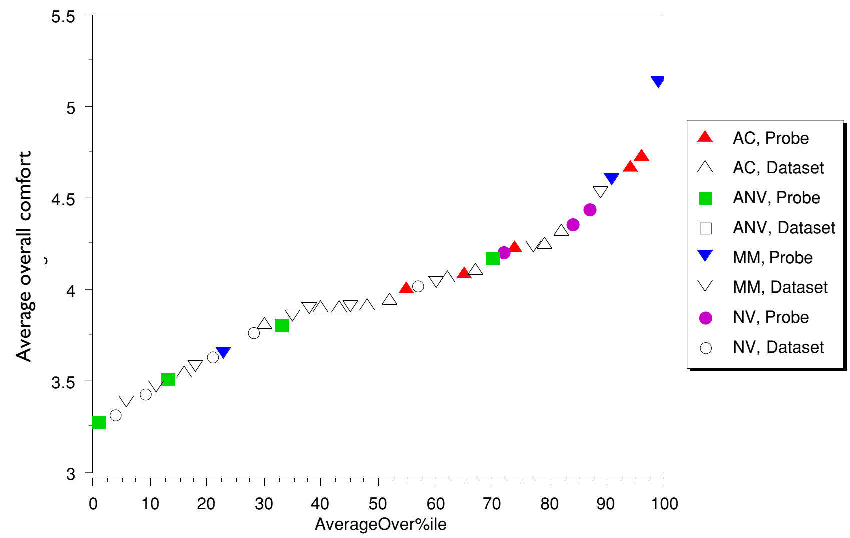
Figure from Probe report: Overall occupant survey scores for comfort by ventilation type

Probe and BUS reference database



Notes

Average Overall score

A score based on the average scores of the following seven summary variables.

TSOver	Summer temperature
TWOver	Winter temperature
AirSOver	Summer air quality
AirWOver	Winter air quality
LtOver	Lighting
NseOver	Noise
ComfOver	Overall comfort

Average Overall percentile

A percentile based on the Average Overall score.

Example

TAN scores an average of 4.73 on the seven summary variables. When converted to a percentile this evaluates to 97. Thus TAN is in the top 5% of the dataset by this criterion.

Scales

Type A. Best on right

Ventilation types

NV	Natural
ANV	Advanced natural
MM	Mixed mode
AC	Air conditioned

Interpretation

For the average percentile variable, all dataset buildings have been a) ranked into order from worse to best (left to right on bottom axis); b) split into four ventilation types c) plotted showing rank against average percentile. The buildings in the top right of the graph are "best" by these criteria.