General Information

Report 31

Avoiding or minimising the use of air-conditioning –

A research report from the EnREI Programme

ENERGY EFFICIENCY

BEST PRACTICE PROGRAMME

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1. INTRODUCTION AND SUMMARY

1.1. Project background

This Report summarises the results of a two-year study carried out under the Energy-Related Environmental Issues (EnREI) Programme, sponsored by the DOE Construction Sponsorship Directorate. It was prepared for the Building Research Establishment (BRE) and has been published in this interim form by BRECSU under the EEO's Best Practice programme in order to disseminate its findings as effectively as possible in the context of other energy efficiency advice and information.

At the Climate Change Convention in Rio, in 1992, the UK committed itself to adopt policies aimed at returning emissions of carbon dioxide (CO_2) and other greenhouse gases to 1990 levels by the year 2000. The EnREI programme was developed to address the implications of any related issues arising from the construction and use of buildings. The avoidance and/or minimisation of air-conditioning in buildings is seen as a priority under this programme.

The purpose of this particular study was to assess the current status of theory and practice in low-energy building design in the UK. When work on the study began, the main target and audience was expected to be people who would normally only consider an air-conditioned building. However, as the study progressed it became clear that the results would also help those who were already designing or considering non-air-conditioned buildings, to enhance the performance of their buildings. This report is therefore targeted at all engineers and architects working with non-domestic buildings.

The study is one of several projects being undertaken by the BRE in the area of air-conditioning. Information on the other projects can be obtained from EnREI enquiries – Telephone: Garston (01923) 664226.

1.2. Aims and programme

1.2.1. *Desk studies*

This report contains summarised information on the present state of the art in the following areas:

- lighting (natural and artificial)
- thermal mass and admittance
- storey height and stratification
- building depth
- 'mixed-mode' design.

Mixed-mode design is not a well-characterised design method, but offers considerable potential for the future. It is important that mixed-mode designs use systems and features to form a single strategy. The building should behave as a mixed-mode building, and not a 'mixed-up one', where no single strategy exists and features may clash or interfere with each other.

The following aspects of each area were investigated:

- equipment and technology
- common practice (recommended and implemented)
- theoretical best practice and opportunities
- future directions.

1.2.2. *Case studies*

Twelve office buildings were monitored as part of this project in order to ascertain how (or how not) to successfully design and manage a non-air-conditioned office building, and the degree to which the features incorporated were working in practice. The buildings, identified only by a letter in this document, were chosen as case studies to give a good spread of performance and features – brief descriptions are given in section 10. This monitoring complemented the desk study conclusions, and was extremely useful in discovering which approaches work in real buildings.

Approximately half of the case studies were also investigated through interviews and questionnaires to assess how the occupants reacted to their environment. Energy consumption data was gathered, where possible, to aid in assessing the possible link between building comfort and running costs. This proved to be difficult for many of the buildings, due to a lack of available data. The performance of each building has been summarised in turn, and then comparison made between buildings adopting similar strategies for the minimisation or avoidance of air-conditioning.

1.2.3. *Guidance material*

All results and recommendations included in this report are based purely upon work carried out as part of this study and, although valid within this context, should be regarded as indicative rather than definitive guidance material.

References have been made to other guidance documents, both within the text and in the Bibliography. Documents produced under the Energy Efficiency Office's Best Practice programme can be obtained from the BRECSU Enquiries Unit on tel 01923 664258, fax 01923 664787. BRE documents can be obtained from BRE Publication Sales on 01923 664444.

2. MAIN FINDINGS

2.1. What should designers be doing?

In order to minimise the use of air-conditioning, the golden rules in designing a building are as follows.

- Make sure that management will be able to tell if something is not working.
- Keep it simple; complexity brings management headaches.
- Minimise the unwanted heat gains.
- Use high thermal mass only if necessary, and if systems can cope with it.
- Choose sensible windows and shading that does not impede their operation.
- Make sure that fit-out and partitioning do not interfere with control strategies or ventilation paths.
- Occupants need to feel that they are in control.
- All default states should be low energy.
- Include sub-metering wherever it might be useful.

2.2. What is going wrong?

Design and management problems found in the course of this study included:

- poor user and central control configurations
- building managers who were not interested or who had too little power
- large or poorly shaded windows giving rise to 'blinds down, lights on' operation
- clashes between windows, shading, controls, furniture, etc
- unnecessarily high installed lighting loads with poor control
- windows that were difficult to operate and/or insecure or leaky
- buildings that were designed before the growth of IT equipment, that now have high heat gains from subsequently installed IT equipment
- buildings that have high heat gains from old lighting systems
- poor task lighting
- heavily tinted glazing resulting in high lighting use
- inflexible or incomprehensible building energy management systems and other control systems
- design parameters that were modified during the design process without adequate thought
- inappropriate fit-outs
- poor initial briefing of the design team by the building owner and vice versa when the building is completed.

3.1. What is acceptable?

Comfort cannot be defined simply by a temperature or, for that matter, even by a set of temperature/humidity/air movement conditions. In recent years it has become clear that it also involves subjective variables such as perceived degree of control by the occupant (whether direct or indirect), management skill, and how interesting a job is.

Insofar as thermal comfort can be defined, the simplest and most powerful yardstick is temperature. Past work by the BRE suggested that summer-time peak design temperatures in a 'formal' office should be 23±3°C, and that in an 'informal' office could be as high as 25±3°C. This difference seems to be related to the degree of perceived control. If occupants can (or believe that they can) take prompt action to cure discomfort, they are more tolerant to changes in the internal environment. This also tallies with general design temperatures which are around 21±1°C for air-conditioned offices and up to 27°C for non-air-conditioned offices. Many continental yardsticks define a maximum number of hours for which the internal temperature can exceed (usually) 27°C. The guidance given in the BRE's Environmental Design Manual for Naturally Ventilated offices (BR86) is currently being updated.

3.2. What influences acceptability?

These limits for the different types of office hide a range of abilities to tolerate conditions. Envelope type is an important element in determining the degree of control; others include:

- control over services, such as lighting, heating, cooling, ventilation, shading
- view
- system responsiveness
- building quality and style of management
- status of each occupant.

Temperature limits chosen for design purposes should only really be used as a starting point, and achieving them will not guarantee a comfortable or popular building. Designers and management should endeavour to widen these limits as far as possible, for instance through effective ventilation, and giving each person control over their local lighting and a window.

The case studies (see section 10) suggest that occupants of buildings which have poor windows, furniture which obstructs ventilation paths and the view (eg building Q), poor lighting control, and an unsympathetic or weak management will have a much narrower comfort zone than occupants in carefully designed and managed buildings.

In mixed-mode buildings, opening windows do not necessarily have to perform as well as in naturally ventilated buildings. In many cases they merely form a psychological safety valve which allows the comfort envelope to be relaxed and the mechanical systems not to have to be as large or to work as hard. Some buildings investigated in this project were reported as feeling too warm at temperatures as low as 24.5°C, whereas others felt fine at 26°C or 27°C. In one case, occupants were willing to forego a proven reduction in peak temperatures from 30°C to 28°C in order not to sacrifice some of the view from their windows.

It can be useful to exploit the fact that people sense temperature differences more acutely than absolute temperatures. The entrance to an office can be made gradually warmer, this will not be detected by the person entering, and even a quite warm room may seem cool after this. Similarly, a building that feels cool when entering from outside on a hot afternoon may be perceived as relatively comfortable even if it is measurably quite hot. However, the beneficial effect of contrast between indoor and outdoor is largely transitory. People are generally much more aware of discomfort than comfort, and more complaints tend to arise when they have no means of alleviating it.

3.3. Comfort theory and research

Conventional theory assesses comfort in terms of directly measurable factors, such as:

- air temperature and temperature gradients
- humidity
- air movement
- radiant temperature
- metabolic rate
- amount of clothing worn by the occupant.

These quantities are either plotted on a psychrometric chart, or are used in a calculation to determine a comfort index. A typical example of this is the Heat Stress Index (HSI) or Predicted Mean Vote (PMV).

One problem encountered in liaising with thermal comfort researchers is that the semantics are still being sorted out. Much of the research has either been done in climate chambers, which tend to heighten individuals' awareness of conditions, or in the field, where the research is often not standardised well enough for context and control. Work undertaken at BRE has demonstrated very different relationships depending upon whether the temperature is under the control of the subject or the investigator. The research is also sometimes too far removed from real buildings to be of much practical use to designers, although it can still provide pointers for more applied research.

4.1. General

The heat gains in a building (the heat which can make the building uncomfortable and must generally be removed over a 24-hour cycle) come from four sources:

- people
- lights
- equipment
- solar radiation.

In order to minimise the need for mechanical cooling, heat gain from these sources should be reduced as far as possible. Gains allowed for in air-conditioning systems can be up to 100 Wm^{-2}. This is often far in excess of what actually occurs, apart from short bursts of solar gain on summer days which can be reduced by shading and absorbed by well-designed fabric (eg passive environmental control).

4.2. Occupancy

Each person in a space emits approximately 100 W into that space. A typical office density is normally assumed to be 1 person per 10 m^2, corresponding to about 10 Wm^{-2}; the mean value in the offices visited was around 1 person per 13 m^2 to 14 m^2, which is equivalent to about 7.5 Wm^{-2}. Some areas of the offices surveyed were occupied more densely than this, suggesting that some form of statistical approach to internal gains would be preferable to the current blanket figures normally adopted.

The balance between sensible heat (conduction/convection/radiation) and latent heat (evaporation) emissions depends upon temperature and humidity, but is not considered in depth here. Total gains are generally accurate enough, as increasing humidity can lead to discomfort in a similar way to a high temperature.

Increasing occupancy gains beyond those intended for the building can bring more problems than might be thought. Not only is there likely to be extra office equipment, but air movement may be impeded and the general feeling of the office space will probably reduce the occupants' tolerance.

4.3. Lighting

Reducing lighting gains has a double benefit: as well as lowering internal heat gains and therefore the need for cooling, it also reduces electrical energy consumption. It is one of the easiest ways of reducing gains, whether at the design stage or after occupation, as lighting can be one of the greatest primary energy consumers (and therefore energy cost items) in a building. Reducing in-use lighting loads by better controls can also increase people's tolerance by giving them extra control over their environment.

Installed lighting loads should be no higher than 10 Wm^{-2} to 12 Wm^{-2}, and in-use consumption of an average of 50% of this, over a year, are practical in most buildings. This is subject to factors such as how well daylit the building is, what lighting level is required, and the occupancy characteristics of the office. The buildings studied were between 11 Wm^{-2} and 28 Wm^{-2} with a mean of around 16 Wm^{-2}. Well specified fittings of 15 or 20 years ago would have given loads of 20 Wm^{-2} to 30 Wm^{-2}, which can now be reduced markedly.

In many buildings, especially in open plan areas, the switching and control arrangements can cause an excessive number of lights to be switched on. There were some notable exceptions to this amongst the Case Study buildings where good lighting systems and controls had been installed (see below).

The energy-saving potential of daylighting decreases as the efficiency of lighting equipment continues to rise and internal lighting levels start to fall owing to the increase in VDU use. Many modern 'green' buildings are therefore designed with a relatively small window area, the preference being to reduce winter heat losses and the potential for overheating, rather than attempting to maximise daylight. Studies by BUS (Building Use Studies) suggest that maximising daylight can also be a fragile strategy as it can lead to unacceptable glare and a 'blinds down, lights on' scenario. More modest ambitions may paradoxically achieve better perceived daylighting and less use of artificial light.

4.3.1. *Lighting levels*

Until the 1970s there was a tendency to match technical developments in office lighting with increased lighting levels, so that installed electrical lighting loads remained approximately constant. This means that lighting levels rose over the years, and in the early 1970s, 1000 lux was often aimed for. Current recommended design lighting levels are 500 lux for general offices and 750 lux for drawing offices, although lower levels are recommended by CIBSE Lighting Guide LG3 where there is substantial VDU use. While this strictly refers to the light required on the working plane, it tends to be applied in a blanket manner over the whole office area. The recent change in the CIBSE Code For Interior Lighting to 'maintained illuminance' will increase initial lighting levels further.

In practice it seems that about 350 lux or less is usually adequate for typical office tasks; if people feel they need more (for instance because of the tasks they are performing, or their age), they can be provided with task lighting on demand. Recent developments in remote control dimmable downlighting systems (such as at case study building G) may reduce the need for conventional ambient/task systems.

None of the case studies demonstrated a good application of task lighting; the task lights were often part of the furniture which shaded the working plane, and often had incandescent lamps. In many cases, they were not movable. There were also many examples of lighting installations delivering well under 500 lux with few adverse reactions.

4.3.2. *Lamp types*

Office lighting equipment should use fluorescent lamps of high frequency, if possible. While some discharge lamps can rival them for luminous efficacy, they have run-up and re-strike time problems which mean that they tend to be left on all day. Even those which give good colour rendering cannot be dimmed without marked colour shifts. In addition the high cost of discharge lamps is not liked by facilities managers. Typical loads (in Wm^{-2}) for a lighting level of 350 lux are given in table 4.1.

Luminaire type	Mains tungsten halogen	Fluorescent	High frequency fluorescent	Best discharge light
Uplighter	61	16	13	16
Normal downlighter	not suitable	10	8	not suitable
Efficient downlighter	not suitable	7	6	not suitable

Table 4.1 Typical load (Wm^{-2}). Higher loads may be required for installations to CIBSE LG3 Categories 1 and 2. Exact loads are also often dependent upon how fittings can be incorporated into office ceiling grids.

4.3.3. *Type of luminaires and quality of lighting*

Ceiling mounted or suspended downlighters are normally preferable on energy grounds to uplighters. The latter have become more popular in recent years with the proliferation of IT equipment, in the mistaken belief that they are the only way of solving VDU glare problems. From experiences in the case study buildings, it was concluded that uplighting generally only works well in rooms with high ceilings, and it is here that glare from downlighters can often be avoided more easily. Floor- or furniture-mounted uplighters can also give problems as they require floor or desk space, which makes them difficult to locate optimally. The tendency to specify uplighters with discharge lamps (or worse still incandescent lamps) reduces efficiency even further and can bring control problems. If uplighting is the only solution to a problem, the light fittings can be linear in design or use groups of compact fluorescent lamps.

CIBSE Lighting Guide LG3 warns that downlighters can have a gloomy affect in rooms where VDUs are in constant use. The case study on building Q, which has reflectors that are almost completely specular, illustrates this problem. A bright band (not so bright as to create a glare source) should be provided at eye level around the edge of an office to relieve this. At Building G (similar in many ways to Building Q), the reflectors are satin finished (not polished) aluminium. This seems to give the right balance between reasonably low glare and avoidance of gloom by providing some illumination of walls.

The quality of a lighting scheme is as important as lighting levels, and lighting efficiency must not be allowed to override all other considerations. However, there is no reason to assume that an efficient lighting scheme will necessarily be unattractive.

The recommended range for the ratio of direct-to-indirect light for most office tasks should preclude sole use of either uplighting (which creates a visual field which is too diffuse) or downlighting with specular louvres, which tends to give harsh downward light. The direction of the direct component varies with the type of lighting scheme, but people appear to prefer 15 to 45 degrees above the vertical, as for natural lighting through windows.

4.3.4. *Lighting controls*

Good daylighting will not save energy unless the controls are in place to reduce the lighting use accordingly. This is generally not a problem in cellular offices, which tend to have a low lighting use anyway. The problems mainly occur in open-plan offices, to which most of this section is addressed.

When not required, lights should be switched off or dimmed to save energy and reduce internal heat gains. This however seldom happens, especially in open-plan offices, where lights are often left on all day because the switches are all located at one end of the office. While the technology to overcome this has been around for a while, the way in which it is used is still not satisfactory in many situations. It is often a case of making use of technology because it is there, and subsequently systems can end up being poorly configured.

The need for extra switching and control goes up with:

- increased daylighting
- increasing area (especially depth) of room
- increasing installed loads
- how close the building is to overheating generally.

In many cases, simply installing extra switches will suffice as long as they are used. BUS studies suggest that this requires their location to be convenient, and their function to be sensible, clear, and obvious. This allows the behaviour of the occupants to mimic that of those in cellular offices.

Daylight linking can be useful in the outer 3 m to 5 m of the office. Extending it to the central zone tends to be risky; the potential for reducing lighting use falls with distance away from the windows, while the potential for adverse glare generally increases. Occupancy sensing is useful in storage and WC areas and corridors.

Timed switch-offs are useful in offices where working hours are moderately rigid. They can also be used in flexi-time offices by ‘pulsing’ the lights a minute or so before they are due to turn off, giving any occupants left the chance to re-initiate them with a local switch or other control. As flexi-hours become more common, thought should be given in each case as to which lights should be kept on whenever the building is occupied, and how to avoid plunging late workers into darkness.

Some of these options are reviewed in BRE Digest 272. It is currently being revised in order to include guidance on new control systems, and advice on how to configure them and avoid making them too management-intensive. A number of general guidance notes can be drawn from EEO Case Studies and other work.

The best systems for open-plan office areas used central computers for (subtle) daylight linking and end of day/lunchtime switch-offs, combined with a remote control handset for each occupant to control the (preferably dimmable) light(s) in their immediate vicinity. Simple overrides are imperative. Lighting should only be turned on automatically for safety purposes, but it should be made available when needed.

Provisions should be made for future fitting out (eg running an unswitched live to every fitting, or having an alterable grid of fittings). The building management must be made aware of these facilities.

The lamp lives and re-strike times must be compatible with the envisaged frequency of switching.

4.3.5. *Maintenance*

The performance of lamps and fittings degrades with time due to the accumulation of dust, loss of coatings, deposits, etc. The overall effect, in lighting levels, can be a reduction from new of over 50% for badly maintained systems, more for uplighters. The designer must therefore ensure that the building management is made aware of these maintenance requirements, otherwise the fall in lighting levels may result in unnecessary task lighting being installed.

Recent work has shown that the overall degradation of output from high frequency fluorescent light fittings is much slower than would be expected from combining data on lamps and luminaires. The reasons for this are not known.

4.4. Equipment gains

One reason for the recent proliferation of air-conditioned office blocks, and also a major potential obstacle for naturally ventilated buildings, has been the growing use of IT equipment in offices.

While the computing power of this equipment has increased at a remarkable rate, the electrical consumption of each piece of equipment has remained quite steady. These loads are generally far below those stated on the nameplate of the equipment, even before diversity and idling time are taken into account.

The maximum likely equipment gains for an office (based on 1 PC per person, 1 laser printer per 5 people, 1 photocopier per 10 people) are about 15 Wm^{-2}, even before diversity is considered. The real reasons for the use of high gains in design calculations are the use of nameplate loads and the reliance of tenants and letting agents on arbitrary yardsticks which they do not understand. In the case study buildings, the highest general IT equipment loads were around 15 Wm^{-2}, with occasional pockets of up to 25 Wm^{-2}. Similar findings have been found in other projects.

Naturally ventilated buildings designed before the proliferation of IT equipment need not suffer unduly. The increase in gains due to the equipment can often be offset by installing more efficient lighting with improved controls, and possibly adding better solar shading if window areas are large, and/or adversely oriented.

In order to keep power consumption and gains down, equipment should be selected with reference to power consumption and efficiency. It is also important to ensure that on/off switches are easily accessible and that the design and/or use of the equipment does not make it very difficult to switch off (eg logging off a network before switching off). The CPU, screen, and all ancillaries should all be turned off from one easily accessible switch. A potential problem is that the people who buy computers seldom discuss (or would even think to discuss) their selection with the office facility managers. Computers with ‘auto-sleep’ capability are now available, and this feature will hopefully become commonplace over the next few years.

4.5. Daylighting and solar gains

4.5.1. *Daylighting*

In most buildings, daylighting can only completely replace artificial lighting during daylight hours for a perimeter zone of up to 4 m deep. Using large window areas to increase daylighting and reduce the use of artificial lighting can backfire as glare problems result in blinds being dropped and all of the lights being turned on. The light distribution needs to be carefully controlled in deeper offices. Light shelves can be useful, but generally reduce glare rather than actually increasing lighting levels at the rear of the room. Good, openable blinds reduce any remaining glare. Perforated blinds are useful, letting some light through even when dropped.

While designers perceive the main visual benefit of windows as introducing daylight into a room, the study of building R shows that occupants can perceive a room as being too dark even when plenty of natural light is available, if a pleasant view is restricted. Simply providing, eg a 2% daylight factor, 4 m into the room, may not always reduce lighting use significantly.

The average percentage daylight factor in a space is a quick way of evaluating how well daylit a room is. For a typical office fitted with clear glazing, the daylight factor (DF) is given by:

$$\overline{DF} = \frac{75\,W}{A} \qquad (4.1)$$

Where:

W = area of glazing

A = total area of all surfaces in room.

For a room 9 m wide and 6 m deep, a floor to ceiling height of 3 m, and a glazing area of 30%, the average daylight factor is approximately 3%. This gives a mean natural lighting level for a standard overcast sky of about 300 lux. The distribution of the natural light in this space means that people near to the windows will probably be able to work without artificial light for most of the time, whereas those at the rear of the office will probably require the lights on for the majority of office hours. Their lights should therefore be switched separately. Equations also exist for calculating the daylight factor at any point in the space, which is a more involved process but is useful for deeper offices.

The CIBSE manual for window design gives a similar expression which can be used for judging the uniformity of daylighting. For a room with a ceiling between 2.7 m and 3 m high, and walls of reflectance 0.5, the effective daylighting depth is calculated as between 7 m and 10 m, depending upon the width of the space. Unfortunately, this analysis makes no allowance for obstructions in the room, which renders it rather unsuitable for many applications, and it cannot be used to predict the depth to which a building can be naturally lit.

Note that neither of the above analyses make reference to glare problems from large windows.

The increase in lighting levels resulting from greater glazing areas tails off as the distance from the window increases. For example, an increase in daylight levels of 100 lux near to the window may correspond to an increase of only 20 lux at the rear of the room. A balance has to be struck between the width and height of the windows. Table 4.2 outlines some of the potential problems in achieving this balance.

Window width	Window height	
	Low	High
Normal	Poor and patchy daylight. Probable ventilation problems	Deep but possibly patchy daylighting; lack of views
Wide	Shallow daylighting or lack of view	Overheating and glare

Table 4.2 Potential problems

4.5.2. *Solar gains*

One common fault in buildings, especially but not exclusively those constructed in the 1960s and 1970s, is excessive window areas. The LT method has suggested that the optimum window area is around 20% to 40% of the internal façade area. The BRE Environmental Design Manual suggests glazing ratios for a variety of building forms. The case study buildings had glazed areas of between 21% and 74%. It was concluded that for most buildings the practical range of glazed area was 20% to 40%, but that judicious use of external shading (eg deep eaves) could allow an increase to 50%, thereby permitting continuous glazing and flexible partitioning.

Below the lower limit, the building can seem too dark and gloomy inside, and occupants may not feel in contact with the outside world. Above this area, the increased solar gains are likely to result in overheating and glare.

External window head shading (eg louvres or eaves) has the advantage of allowing retention of an external view, which is an important factor in increasing user tolerance. Permanent shading within the field of view is unpopular. Internal shading is more flexible and will nearly always need to be used to augment external shading. Internal shading is not as effective as external shading in reducing solar gains. It can interfere with ventilation if the window/shading system is poorly configured, but it is generally easier to design/specify, and is more controllable. In all the case study offices, if shading had not been fitted in the original design it had either been added or was about to be added. Tinted glazing does not discriminate enough between light and heat, and often increases lighting use as the exterior appears duller than it really is.

Adjustable external shading needs cleaning and servicing. Automatic control is often not popular unless controlled impeccably and provided with overrides. In one of the case study buildings, external blinds were translucent and set away from the windows to maintain visual contact with the exterior, but this was still not very popular.

The impact of solar gains in a space can be evaluated if one considers (for instance) a SW facing window with internal venetian blind, which in summer will receive maximum radiation of approximately 800 Wm^{-2}. Of this, approximately 40% (320 Wm^{-2}) penetrates the space. If we consider this to be distributed over a zone 6 m deep, the gains per unit floor area for different glazing areas on a July day are as given in table 4.3.

Window area	Peak afternoon gains for floor area facing (Wm^{-2})			
	N	S	E	W
20%	4	17	4	25
30%	6	25	6	38
40%	9	34	9	50
50%	11	42	11	63

Table 4.3 Gains on a July day

It is evident from this that solar gains can easily be the largest contributor to the peak gains in an office, and direct radiation may make this worse. Of course, the sun will not be at full intensity for all of the day, or every day in the year. However, table 4.3 gives some idea of the degree to which window size and shading can influence gains in a space. In a well-designed building, these large transient gains can be dissipated through interception and a combination of absorption by the building fabric and ventilation.

It is interesting to note that the 'thermal efficacy' of natural light, ie the amount of light delivered per unit of heat dissipated, is approximately 100 lm W^{-1} to 120 lm W^{-1}. This compares with the best artificial light sources.

4.6. Overall gains

The use to which the office is to be put will determine the usage of lighting, equipment, and shading, and hence the overall total of the mean and peak gains. This total of office gains in turn determines the design and proposed operation of the building. While some buildings have future occupants who are known, this is not always so, and a 'sensible' level of gains and mode of operation have therefore to be decided upon.

Lighting and occupancy gains can be pinned down reasonably accurately provided that sensible guidelines are followed. A suitable range of probable equipment gains should be chosen, allowing for high gain areas and possible mixed-mode strategies.

Average solar gains depend upon a number of factors, including the room depth, the direction that the window is facing, window shading, and also shading offered by surrounding buildings. It is not realistic to suggest a likely value for most cases (see above for examples of peak gains).

Whilst the data here is related to good design, note that lighting gains in many existing buildings (and unfortunately in many new buildings) will be higher than those used for the data in table 4.4.

Gains/floor area (Wm^{-2})	Low gain	Medium gain	High gain
Occupancy	5 - 8	8 - 11	11 - 15
Lighting (incl. diversity)	3 - 5	6 - 9	10 - 14
Small power	0 - 6	6 - 12	12 - 20
TOTAL	6 - 16	18 - 30	30 - 50

Table 4.4 The afternoon peak solar gains (eg for a July day) should be added to this data (see above) - and Table 4.3

5.1. What is admittance?

The admittance of a material (*Y*) is its ability to exchange heat with the environment when subjected to cyclic variations in temperature. It is measured in $Wm^{-2} K^{-1}$, and is defined such that if the temperature in a space at any time deviates from the mean by an amount *T*, then the surface absorbs *Y T* of power per unit area. Therefore, the peak absorption of power in a space is equal to:

$$\Sigma A\, Y\, (T_{max} - T_{mean}) \qquad (5.1)$$

Where

A and *Y* = the area and the admittance respectively of each surface

or

$$\Sigma A\, Y\, T_s \qquad (5.2)$$

Where

T_s = the temperature swing (from the mean)

Admittance is dependent upon a number of material variables – notably density, thermal capacity, and the thermal conductivity of the first 100 mm or so (for a 24-hour cycle) below the surface. It is also dependent upon the time period of the oscillations, and is subject to the resistance of the film of air at its surface. A structure can absorb short-term fluctuations more easily than long-term ones.

The admittance of common constructions varies between 0.7 and 6. The upper limit is governed by heat transfer across the boundary layer. The resistance of the air film at an internal wall surface is 0.12 $m^2 KW^{-1}$. As this resistance is in series with the admittance of the material it generally places an upper limit of around 8.3 $Wm^{-2} K^{-1}$ on admittance values.

Admittance is not the same as mass, although they are often related. Placing an insulating layer or an air cavity in front of a heavy surface, in effect, isolates it from the environment in the room and reduces its admittance markedly.

It is sometimes stated (eg CIBSE guides) that the admittance of a thin member (eg glazing) is equal to its U-value. This can confuse the issue somewhat. While the admittance of a structure is used in conjunction with a temperature swing about a mean, a thin element will simply pass heat to outside, and must be used together with the temperature difference between inside and outside, not the internal temperature deviation from its mean value. This is often not made clear in the literature.

5.2. Effects of thermal mass and admittance

The equivalent of the above equation of power absorption for ventilation is:

$$C_V\, \Delta T = \left(\frac{1}{0.33\, N\, V} + \frac{1}{4.8 \Sigma\, A} \right)^{-1} (T_{int} - T_{ext}) \qquad (5.3)$$

where

N = ventilation rate (air changes per hour, ach)

V = volume of space (m^3)

For low ventilation rates (typically < 10 ach) this approximates to:

$$C_V\, \Delta T = 0.33\, N\, V\, \Delta T \qquad (5.4)$$

The balance between the effects of admittance and ventilation can vary throughout the day. The heat removal offered by the admittance of a structure depends upon the variation of the internal air temperature from its mean value. It is therefore at its maximum value when the internal temperature is at its maximum. At that time, heat removal by ventilation will be least effective, as the temperature difference between the interior of the building and ambient will be small. Because of this, the daytime ventilation rate does not play as important a part in determining peak temperatures as the corresponding night-time value. This is especially true in heavyweight buildings. If a building is actually cooler than the ambient temperature, then the ventilation rate could be restricted to a nominal value of, for example, 1 or 2 ach. In practice, this is rarely achieved or necessary, as the occupants will open windows if possible to get air movement and as a psychological relief, but it sets the basis of how a heavyweight mechanically ventilated building could be run.

Heat which is stored in the building structure during the daytime must be removed at night to avoid the building temperature rising steadily during the week. This is often overlooked or implemented badly by designers and occupants, either because of poor window design, lack of occupant or management education, or badly configured systems. Ventilation rates of 2 ach to 5 ach should be considered in the absence of better information. The actual rate will depend upon many factors such as heat gains, building design, and building operation. Openings for natural night ventilation must be secure against intruders, birds, weather and vandals.

The heavyweight case study buildings which relied on natural ventilation at night had good stability (although interestingly, no better than some of the more lightweight constructions). Despite this, problems of security and lack of management knowledge and direction precluded effective night ventilation. Consequently heat losses at night were minimal, and the buildings had no chance to cool down.

These problems can be overcome in a well-managed building. Some of the mixed-mode buildings also had problems with obtaining effective night ventilation.

- At building P, the temperature mismatch between floors due to the exceptional cooling available on the ground floor meant that night ventilation, which cools the upper floors to a suitable temperature, made the ground floor uncomfortably cool first thing in the morning.

- At building U, the boilers were enabled whenever the central air handling units (AHUs) or the fan-coils were operating – this wasted energy. On the majority of nights, condensation limits turned off the whole ventilation system early in the morning when the most cooling was available. As mentioned elsewhere, inflexibility of the controls and the BEMS meant that this could not be rectified without spending a great deal of money.

5.3. Driving heavyweight and lightweight buildings

Heavyweight buildings are not necessarily especially difficult to design or manage well. The fact that the summertime temperatures in the high admittance, naturally ventilated buildings examined were unpopular only emphasises the degree to which avoidable design and management problems were widespread.

Lower admittance buildings need to get rid of most gains as they happen as the fabric cannot absorb as much energy. The feedback loop is rapid, and occupants see an almost instantaneous effect from the opening of windows. This can require very high daytime ventilation rates as the temperature differential between inside and outside is not as great in the daytime as at night and greater air velocities are required to give a feeling of coolness. The management of this appears to be easier than that for heavy buildings, as opening windows during the daytime is an instinctive reaction of the occupants, and security worries are not a problem. However, in a heavyweight building, by the time occupants feel the need to open windows, the ventilation will have little effect other than providing some perceived cooling due to increased air movement.

In principle, there is no reason why heavy buildings should have a higher mean temperature than lightweight ones. In practice, as gains stored in the fabric are not released during the day or at night this is generally observed.

For high admittance buildings to operate effectively, what is in effect a 12-hour feedback loop must function in order to use night ventilation sensibly. This can be operated by security staff, provided that they have been adequately trained. Unfortunately, this is not often the case, and security staff are not always under the control of the occupants anyway.

If gains are not particularly high and air movement is good, then a well-managed building does not necessarily need a high thermal mass to perform satisfactorily in the summer (eg building G). A high thermal mass is not a guarantee of a comfortable environment.

5.4. Should I build heavy or light?

A well-managed heavyweight building can cope with a wide variation in gains, and is indeed the best solution to the problem if effective night ventilation can be ensured. If no such assurance can be given (for instance, if occupants need to open windows and if there are possible security worries), then a high thermal mass may store up problems. Where gains are not too high, the thermal mass can be reduced accordingly, as the excess heat capacity is not needed.

If good management of a well-configured ventilation strategy will ensure night ventilation, then the thermal mass of the building can be as large as possible, to allow for future changes in use and occupancy. If night ventilation cannot be assured, a lower thermal mass should be chosen. Attempts must then be made to minimise solar and internal gains and maximise useful daytime ventilation, with a suitable margin for error and some allowance for future changes.

For a given set of gains, the required ventilation rates and admittances can be calculated for internal and external conditions of (for instance) 23±3°C and 20±5°C respectively. If this indicates that a heavyweight structure with significant night ventilation is necessary to get the temperature down to these levels, then the following questions should be asked.

- Are the gains and ventilation rates assumed realistic? Are the gains calculated using real power consumption values? Do the values include allowances for diversity?

- Can the window area be reduced or shaded more effectively?

- Can window design and internal layout (if applicable) be altered to increase ventilation rates and air movement ?

- Can the high gain areas be spread around to share the load, alternatively can they be grouped and treated separately (by isolation, extraction or local air-conditioning)?

If a heavyweight structure and significant night ventilation are still considered necessary after answering these questions, then its operation should be made obvious to the management and occupants and possibly automated. However, effective automation needs to be carefully thought through and give good feedback information to management.

Cellular buildings often have a high thermal mass, regardless of the materials used, as the extra surfaces increase the thermal capacity. This can balance the effect of the lack of cross-ventilation but effective night ventilation needs to be assured.

Heavyweight buildings take longer to heat as well as cool down. In winter, the longer pre-heat periods can require a larger plant and increase heating costs. However, these costs tend to be small in comparison to those of mechanical cooling and are reducing as buildings become better insulated and lose their heat more slowly overnight. Alternatively, trickle charge buildings could be considered, with (for instance) continuously operating plant of a smaller size.

5.5. Other factors

5.5.1. *Slab ventilation*

One reason why thermally lightweight buildings are often built is that architects (and others) demand suspended ceilings and raised floors for servicing, partitioning, and acoustic reasons, thereby isolating the floor slabs from the thermal environment. Underfloor ventilation can help to restore heavyweight behaviour, as seen at buildings P and T.

Typical values of heat transfer at building P were up to 5.5 $Wm^{-2}K^{-1}$. At building T, where the flow pattern did not seem to be so well optimised, the heat transfer was not as efficient. The amount of heat transferred into the slab is limited in approximately equal proportions by convection and by the thermal conductivity of the material, so that there is no great benefit in increasing convective heat transfer only.

The rate of heat transfer between the air stream and the slab is a balance between attaining turbulence, and allowing the air to reside in the void area long enough for sufficient heat transfer to occur. The air velocity determines the heat transfer coefficient and the time of residence in the floor void. This must all be balanced against the fan power required.

A system which has been the subject of a lot of work recently is Termodeck. This uses a hollow slab as a supply air duct to the space. The main finding here has been that much of the heat transfer occurs at bends in the air path; this has implications for similar applications of these techniques.

5.5.2. *Ceilings*

Conventionally, a heavy ceiling has tended to mean exposed slabs or concrete coffers. There is often a worry that these have poor acoustic properties, and they can also be unsightly unless expensive finishes are applied.

These problems can be tackled without resulting in a lightweight ceiling. Examples in the buildings visited included:

- building I, having an open-plan ceiling which was not lined with plasterboard but with a high admittance, cement-bonded chipboard
- building K, having suspended ceilings, installed in sections, where a 50 mm gap around the edge of each acoustic tile, located in a coffered ceiling, was enough to allow interaction between the internal environment and the structure, and give the building the thermal stability of a heavyweight building
- building S and building U having sprayed acoustic plaster.

5.5.3. *Furniture*

Designers should be aware that internal partitions and furniture in an office increase the admittance of the building by approximately 1 WK^{-1} per m^2 floor area. However, a full fit-out by interior designers can also reduce admittance markedly by obscuring exposed slabs and walls.

6.1. Function

Ventilation fulfils a number of different functions:

- health: respiration, odour avoidance and pollutant removal
- cooling: removal of heat produced by internal and solar gains, both during the daytime and at night
- comfort: provision of air movement to increase perceived cooling.

Approximate values for the ventilation rates needed for these functions are shown below in table 6.1.

Requirement	ach	$ls^{-1}\ m^{-2}$
Health	0.5 to 1	0.4 to 0.8
Comfort	1 to 5	0.8 to 4
Cooling	5 to 30	4 to 25

Table 6.1 Ventilation rates

A ventilation system (whether natural, mechanical, or some mixture of the two) should be able to cope with all of these situations and provide draught-free ventilation with a good degree of local control. As can be seen, these ventilation rates vary widely. Although achieving them with either a single type of window or a single fan speed is impractical, people persist in trying to do so.

6.2. Methods of ventilation

The method of ventilation and/or cooling chosen for a building should depend upon the likely gains and the admittance of the building. High gain buildings are more likely to need mechanical ventilation (or even mechanical cooling) than low gain buildings. Where intermittent high gain buildings require a heavy mass, mechanical ventilation may be necessary to make full use of it. Note that for high 24-hour gains thermal mass is not so useful.

6.2.1. Natural ventilation (including window design for ventilation)

The driving forces for natural ventilation are temperature differences and wind. The pressures generated by these mechanisms are quite low (typical stack pressures 0.3 Pa to 2 Pa, wind pressures 1 Pa to 35 Pa). Stack pressures can be increased by raising storey heights (although this can only have a limited effect), or by venting via atria. Stack pressures are more controllable and reliable in the summer, increasing with rising temperature differences. Excessive infiltration in the heating season must be avoided. Wind pressures need more careful harnessing as they can vary enormously, but their greater magnitude generally makes them more useful in offices.

Because of its very nature, natural ventilation is thought of as being easy. Window design is hardly given any thought other than with regard to maintaining elevations and keeping costs down. This is a huge misconception. As previously stated, besides functions such as daylighting and providing a view, opening windows should also be able to cope with a wide variety of ventilation requirements:

- **i.** trickle ventilation for winter use without causing cold draughts.
- **ii.** night ventilation via a secure and weather-, bird-, and sometimes insect-resistant opening. (If at high level, the same openings can also assist daytime cross-ventilation in an open plan office without causing uncomfortable or paper-blowing draughts near the windows).
- **iii.** air movement on still summer days for perceived cooling through a large, opening area.
- **iv.** normal summer use giving high air change rates for a wide range of wind speeds, without permitting the wind to blow papers off desks.

Item **iv** requires a medium-sized opening positioned at mid-level.

It is usual to have a group of opening windows at different heights in older buildings. This has been replaced in more recent buildings by one opening element, often a tilt-and-turn window. On tilt setting, these generally provide too much air for winter and too little for summer. On turn setting (which is only really intended to allow cleaning), the windows tend to blow about, clashes with desks often occur, and draught-free ventilation is difficult.

From the case study buildings it was concluded that items i and ii above can be performed by the same element at high level providing it has a variable opening. Ideally, items iii and iv each require a dedicated element, although one proves adequate for most of the time. (The recently developed Colt Interactive Window System is one response to these requirements. This new window is shortly to have its first commercial application and its performance will be monitored.)

At building R it was found that inward-opening hopper windows were popular at cill and ceiling levels even when the workmanship was poor. Also, providing a choice of which window to open allowed the occupants to get the environmental controls working to suit their preferred office layout, and not vice versa. A degree of over-provision in window-opening opportunities should not therefore be seen as wasteful; choice forms an important part of effective natural ventilation strategies.

Sash windows can give problems, especially if their frames are thin in section, and do not have traditional glazing bars that can be grasped to allow people to open or close the upper sash easily. People take the easiest route to achieving short-term comfort, so that if windows are difficult to open they simply resort to desk fans.

Openable vents and windows must operate under a range of wind speeds, directions, and temperature gradients. The flow paths must match the desired routes, especially after fit-out.

Vents and windows are a source of potential noise and dust in certain environments. In practice they can be acceptable if the location is not near a major road with heavy traffic, and the noise and pollution requirements are not too strict. Mechanical ventilation and air-conditioning systems do not necessarily solve all of these problems.

Air movement can be used as a tool to make people feel cooler, but should be dealt with sensitively. Whereas a desk fan consumes typically 50 W and serves 1 person (ie 4 Wm^{-2} to 6 Wm^{-2}), high level punkah fans use a similar amount of power but can serve a large area. When used in winter at a slow speed high level punkah fans can also reduce stratification in tall spaces. Outlets for air-borne heating and ventilation systems must not be positioned close to occupants, especially at ankle or neck level.

Dedicated vents can be insulated (reducing fabric losses in winter), and can be designed to increase sound absorption and improve security. They can also provide ventilation without increasing solar gains. Although they can be a solution for trickle and night ventilation, they will generally not have a sufficient area for summer daytime air movement. If they are simply designed as opaque parts of the window system, occupants may react to the lost opportunity for additional visibility, as at building L.

6.2.2. *Mechanical ventilation*

Mechanical ventilation systems resolve a number of problems associated with natural systems. They require much smaller openings, can be easier to control, and provide sound absorption and security. However, they consume electricity and heat the air. Fans can in theory operate at better than 80% efficiency, but in practice less efficient units tend to be specified to save money, or provide a design safety margin. The loss in efficiency is dissipated as heat. Systems can have fan gains of up to 2°C, which can make the difference between a comfortable building and one that is too warm. They can also render night ventilation useless for much of the night.

As mentioned earlier, if a building is sealed and mechanically ventilated, occupants will react to the loss of control of their environment associated with the loss of opening windows. They may demand a higher degree of environmental stability which might not be possible without mechanical cooling. Full mechanical ventilation also tends to require significantly increased air change rates than where natural ventilation is additionally available. This increases HVAC capital and running costs unless variable speed control is possible and effective. Local control should follow the rules set out in section 9. If opening windows are also used, the system must be configured so that these do assist rather than undermine the efficiency of the ventilation system.

Care should be taken that grilles are not positioned where they are likely to be obscured by furniture or produce an unpleasant draught. The likelihood of future partitioning needs to be considered. If floor grilles are used, the carpet tiles and the floor tiles should be of the same size to enable them to be moved easily. Modern fixings make the attachment of carpet to floor tiles easier than it was in the recent past.

Mechanical ventilation is also sometimes used to provide wintertime background ventilation, reducing the heat losses incurred by opening windows. If configured properly, this can be a useful energy saving technique, but a calculation will need to be done.

The current driving force behind most air-conditioned buildings is financial (they are seen to command a higher rent). Initially air-conditioning occurred because refrigeration could cost less, and use less energy, than pushing lots of air around the building. This should be remembered when designing a mixed-mode or mechanically ventilated building; energy savings from omitting air-conditioning can sometimes be illusory.

Displacement ventilation has been widely discussed recently, and many offices with an underfloor air supply now claim to have it. This is seldom true for the following reasons.

- **i.** For reasons of economy, designers usually specify large swirl floor diffusers. These are not recommended for displacement ventilation as the flow pattern encourages mixing of the room and supply air, and can also cause local discomfort. Special displacement wall terminals or floor ‘slump’ diffusers should be used. They handle approximately 25% of the air volume of the swirl diffusers, and so increase the cost of the installation.
- **ii.** In mixed-mode designs, the turbulence introduced by the natural ventilation tends to undermine the displacement effect. Desk fans have a similar effect.
- **iii.** For background mechanical ventilation, frequently only 2 ach or so will suffice. However, with typical occupancy and internal gains the volume of air displaced in the convection plumes from people and equipment is often several times as high as this, so much of the air will recirculate.
- **iv.** Even where the supply and plume air flow rates balance, recirculation can still occur due to convection effects at the perimeter of the room, either downdraughts from windows or thermal bridges, or updraughts from perimeter heating. However, in well-insulated buildings these effects can be minimised.

6.3. Mixed-mode

The use of mechanical ventilation in conjunction with openable windows can be approached in a number of ways.

1. The building can be fundamentally mechanically ventilated, and the mere presence of openable windows provides a psychological safety valve which allows more variation of the internal conditions.

2. The building can be fundamentally mechanically ventilated, and the presence of openable windows can provide some extra ventilation and air movement.

3. The building can be fundamentally naturally ventilated, and the mechanical system provides extra ventilation if it is needed.

Mixed-mode design can be applied in several different ways, which can co-exist within a building, and even within a single space.

6.3.1. *Contingency planning*

Contingency planning is useful when one does not know how the building is to be used. A minimum level of environmental control can be provided, with provision for further control if required at a later stage. Examples of this include:

- building G, which was a compromise between the natural ventilation that the client wanted and the possibility of air-conditioning that the developer demanded. There is room above the suspended ceiling, below the raised floor, and also in the risers and plant room for air-conditioning plant, ducts, etc. to be installed if any future occupant so wished.

- the mechanically ventilated mixed-mode buildings which could be fitted with cooling coils in future if greater cooling was needed; or if local sensible cooling was added, a mechanical fresh air supply would already be available.

6.3.2. *Zoned systems*

This is where different systems are used to serve separate areas of the building, for instance mechanical ventilation or local cooling in computer or copier rooms, with natural ventilation in the general office areas. This encourages localisation of 'hot spots', and so reduces the load in the general office areas. Examples of this include:

- building L, where the offices were naturally ventilated with a low level of extract in the centre of open-plan areas, and the conference rooms were air-conditioned. (This latter feature is quite common.)

- building Q, where some of the ground floor offices were mechanically ventilated due to the security problems of openable windows

- building S, where the management suite was air-conditioned, and the remainder of the building had mechanical ventilation with opening windows.

6.3.3. *Changeover systems*

Changeover systems are those where different systems are used according to the season. As an example, mechanical ventilation could be used to improve air movement and night cooling in summer and to provide background ventilation with heat recovery in winter, with only natural ventilation in spring and autumn. Although potentially a low energy approach, the management implications of changeover can be problematical and the systems tend to get operated in parallel (see 6.3.4).

6.3.4. *Parallel/concurrent systems*

This is the type of building which is most commonly referred to as mixed-mode, where mechanical ventilation, with or without cooling, operates in parallel with openable windows. Buildings O, P, S, T, and U fall into this category. The possible clash between the natural and mechanical systems has to be considered carefully, in all seasons.

7. STRATIFICATION AND CEILING HEIGHT

7.1. Stratification

In winter, temperature gradients are generally wasteful, as the heat is required at occupancy level, not at ceiling level where it mainly contributes to increased heat losses. Mixing may increase contaminants at low level, possibly requiring increased ventilation rates. If these are created by higher velocity air movement, higher supply air temperatures may be needed (see below).

In summer, stratification effects can result in higher temperatures at ceiling level allowing lower comfort temperatures at occupancy level.

Excessive stratification can result in discomfort if the temperature difference between the head and ankles exceeds 3°C to 4°C. This is equivalent to approximately 2°C m^{-1} to 3°C m^{-1}, which compares with the 0°C m^{-1} to 1°C m^{-1} found in the occupied zones of the case study buildings.

The presence and magnitude of a temperature gradient depends upon many factors, the chief ones are:

- high temperature sources (solar hot spots, convector heaters, people, computers, black roofs, coffee machines etc.)
- the mode of ventilation, including direction of air currents and height of highest opening windows.

An obvious example of the latter factor is at the top of a glazed stairwell with no opening windows, where temperatures can reach very high levels.

At Building Q, two similar spaces displayed widely varying stratification. An open office area with computers showed a temperature difference of around 2°C, whereas a highly obstructed area did not show any stratification at all. This may be due to the ventilation passing across the open office unimpeded, whereas the cross-ventilation in the more crowded area was forced to 'scour' the ceiling.

At Building R, in the top-floor mansard rooms, the window head height is around 1.8 m in a room around 3 m tall. The upper section of this room got as warm as 36°C, some 5°C higher than that in the occupied zone of the room, as internal and external fabric gains accumulated just below the ceiling.

7.2. Ceiling height

Higher ceilings increase the admittance of the rooms and can therefore help to reduce peak summer temperatures if managed well. An increase of ceiling height from 2.5 m to 3.5 m in a medium weight 'typical' office can reduce peak temperatures by approximately 1.5°C if the area of glazing and the ventilation rates are kept constant. However, there could be cost implications.

Other significant effects of high ceilings are to allow high level ventilation paths for the removal of contaminants, space for future ducts (primitive mixed-mode design), and to increase the feeling of spaciousness. They will also allow an increase in daylighting if window head heights are increased, and a greater air volume per occupant which means that pollutants can build up less rapidly. High ceilings will allow space for the pollutants and gains to gather before being removed by extraction or cross-ventilation.

Comfort is also affected by radiation losses from the body to the walls and ceilings. In heavyweight buildings where the temperature of the structure is likely to remain fairly constant, higher ceilings will enhance comfort during the summer.

The psychological effects of high ceilings may be more significant than the physical ones, as a high ceilinged space tends to be more visually interesting as well as feeling less claustrophobic.

7.3. Ceiling fans

Ceiling fans are generally very effective at mixing the air in a space, and providing significant air movement over a wide area. In high-ceilinged spaces in winter this can reduce heating bills; in summer it can produce perceived cooling by the movement of air over the occupants. This is in direct opposition to displacement ventilation, which aims to keep the warmer and more polluted air away from the occupants. Rohles et al estimated the trade-off between air velocity and air temperature as 0.22 $ms^{-1}°C^{-1}$, so that at an air velocity of 0.8 ms^{-1} (the maximum suggested by ASHRAE), an effective temperature depression of 3.7°C is attained. Therefore, unless stratification levels are severe (>1°Cm^{-1}), the cooling effect of an array of suitably positioned ceiling fans can outweigh the effect of the mixing of warmer air.

8. BUILDING PLAN AND LAYOUT

8.1. Building depth

8.1.1. *Factors determining the depth*

The depth of the building plan (ie the maximum distance from a window) is crucial in determining the likely success of naturally ventilating an office. While guidelines exist (derived from considering daylighting and ventilation for heat removal) as to the maximum practical depth such as 15 m (window-window) or 8 m (single-sided), there is obviously more to this issue than simple depth. Ceiling height, window and shading design, and internal layout and fit-out all have a part to play.

8.1.1.1. *Ventilation*

The deepest naturally ventilated buildings studied (K, L and Q) were 15 m from window to window, and while the lack of air movement was a problem in two of these, this was probably due more to internal clutter and poor window design than the depth. Three mixed-mode buildings of around 15 m deep were also studied. On the whole they performed satisfactorily, and the deepest building, at 18 m deep, did not suffer from a lack of air movement. Of course, in the mixed-mode buildings, it is extremely difficult to decide where the air movement originates. With natural ventilation only, winter conditions could actually be the most taxing, as trickle ventilation needs to reach the centre of the room.

Recent work at the BRE has shown that for a completely unobstructed office it is possible to achieve an acceptable level of air quality and circulation through single sided ventilation at depths of up to 10 m. While this should be treated with caution, it indicates that there may be the opportunity to go to slightly deeper spaces than are normally thought possible. This will depend upon the ventilation paths being effective, and the increased amount of air entering through the windows not causing local discomfort for the people sitting at the perimeter, as they have control over the internal environment as a whole.

8.1.1.2. *Psychological effects*

As mentioned earlier, the tolerance of occupants to environmental change decreases as their perceived control is reduced. Therefore, a person sitting in the centre of a deep-plan space with no external view or ‘safety valve’ openable window will be less tolerant of (for instance) summer overheating than someone situated at the perimeter. If, as a result of this, the central zone has to have a more closely controlled environment then so may the rest of the office.

8.1.1.3. *Daylighting*

The other major factor determining the maximum depth to which a building can be passively serviced is daylighting. Various limits have been set on the maximum daylighting depth. In section 4, upper limits of 4 m were mentioned for daylighting to suffice during daytime hours. Rooms up to around 7 m deep can appear uniform enough, but will generally require some artificial light most of the time, unless extra measures are introduced. The window areas needed to get useful daylighting beyond this can result in glare problems and trigger a ‘blinds down, lights on’ situation.

While the importance of daylighting in defining the maximum practical depth of a naturally ventilated building is perhaps not as important as ventilation and psychological effects, the possible energy implications of artificially lighting some office areas all of the time should not be neglected, although the effects of this can be mitigated with sensible controls.

Daylight linking in the offices studied was not always successful, although the more modern high frequency fluorescent lighting systems coped better than those with discharge uplighters, and in particular furniture- and floor-mounted ones, where the light fitting positions had become compromised over the years as the occupancy and clutter had increased.

8.1.2. *Other effects of and constraints on building depth*

8.1.2.1. *Financial*

The major reason behind the huge growth in air-conditioned office space in the last 10-15 years is that the rental premium payable for this space is greater than the extra cost involved in its construction. This has been compounded by corporate standards and the fear of overheating from equipment heat gains, which were vastly overestimated in the 1980s. Once air-conditioning has been decided upon, then daylighting becomes the only potential reason for using a narrow plan. As energy efficiency does not come very high on the list of priorities in an air-conditioned building, it is not surprising that achieving a narrow plan ceases to become important. In any event BUS studies indicate that in sealed buildings people use daylight less than in buildings with openable windows.

The cost of land in many urban environments means that the maximum floor area is built on each piece of land to maximise returns (although there may be limits set by the planning authorities, see 8.1.2.2.). The best way of doing this is often to use a deep floor plate. This allows greater flexibility of layout and reduces the ratio of the perimeter of the building to its area. The latter is an important element in the cost of a building.

Institutional lenders tend to work to a formula when deciding upon funding for a building. This typically includes air-conditioning with control to 21±1°C, lighting to 500 lux or 600 lux, and floor power loadings of 25 Wm^{-2} to 100 Wm^{-2}. These criteria are fairly inflexible. The allowance for floor power loading encourages the use of air-conditioning when the probable actual small power loads would not merit it. This argument could possibly be used to get mixed-mode design into wider usage.

8.1.2.2. *Planning authorities*

The depth of building plan has a profound effect on the densities that can be achieved (ie office floor area per acre of land). In urban environments it may be largely determined by the plot ratio or height restrictions as set by the local planning authorities.

8.2. Building layout

The layout of a building is important in that it can determine control configurations, whether ventilation paths will work, and how much contact occupants will have with the outside world.

As much information as possible should be sought from prospective occupants as to what their proposed layouts will be so that systems can be configured correctly. This will not be possible in many cases, so the building should be designed to accommodate a reasonable amount of flexibility without over complicating or compromising the design. This should not be too difficult for a well-designed lighting system, but ensuring that ventilation paths are maintained can be very difficult. Examples of problems encountered in the buildings studied include:

- at building Q, screens obstructed cross-ventilation and view
- at building I, full height partitions have been erected across a balcony which was intended to be left unobstructed; many staff now complain about the lack of air movement throughout the building
- at building O, when cellular offices were created from an open-plan area at least one office had an extract grille but no supply
- at buildings R and T, when cellular offices were created from an open-plan area the lights in the cellular offices were still switched from a central switch down the end of the corridor
- in all of the buildings which had floor supply air vents (P, T and U), the floor tiles and carpet tiles were on separate grids. This means that new carpet tiles would have to be cut in order to move each vent, consequently the vents will never be moved and this could lead to problems for the user.

Office layout is also part of the fit-out. The people who perform the fit-out generally have a series of standard grids of office furniture which they simply use to form a jigsaw in the office space, often neglecting the operation of windows and the siting and operation of many other controls. Lighting installed as part of a fit-out is also often inefficient and poorly controlled. The design team should have an input into the fit-out procedure – whether they actually design it, are retained as advisers, or produce a briefing guide which must be taken seriously by the client and fit-out team.

Grouping high heat gain equipment into mechanically ventilated and/or cooled zones may reduce gains in other zones sufficiently for them to not require cooling.

8.3. Building orientation

While it might be thought that south-facing windows are most likely to give rise to overheating, windows facing between west and south-west pose a greater danger due to:

- **i** the problems of shading when the sun is low in the sky
- **ii** the peak in solar intensity occurring at about the same time as the maximum ambient temperature
- **iii** the peaks in **(ii)** both occurring towards the end of the day, when gains have had a chance to build up and occupants may be starting to clock-watch.

8.4. Other issues

Occupants' tolerance of the internal environment is dependent upon how pleasant the building itself is to be in. Internal visual variety and vistas can be used to increase this tolerance. This can be achieved using (amongst a number of measures) atria or architectural features.

9. DESIGN CONTROL AND MANAGEMENT

This section discusses a number of issues affecting the design and subsequent use of the building which may appear secondary, but which have been shown to have a direct effect on the success of all buildings and in particular those which are naturally ventilated.

9.1. Design process

New projects usually take at least 2 to 3 years from preliminary sketch design to handover. During this period the initial design strategies can become gradually compromised by subsequent decisions and changes. They may be gradually diluted as different personnel get involved, through evolution of the brief, cost cutting, or merely a lack of understanding of the strategic issues by the team as a whole.

Reported examples of this include background lighting levels shifting towards general lighting levels, and localised switching forgotten during fitting out. A method of monitoring the design targets is therefore recommended. This could mean having somebody who is not otherwise involved in the project come in every few months (or more frequently at certain stages of the design) to review the design against the original criteria.

Strategic and detailed features which are vital for such a building to work should be stated as basic requirements at the outset and be suitable identified and budgeted. These can include the lighting and its controls, window design, exposed thermal mass if needed, sensible fit-out, etc. In many cases, these features become victims of cost-cutting or even cost planning, using elemental costs derived from historic data which might not be relevant to future needs. The effects of removing or changing each feature should be analysed in depth.

A number of decisions made during the design stage affect the maintenance requirements. This information should be discussed with owners and occupiers as there is a tendency for operation and maintenance requirements not to be fully appreciated on both sides. The information issued should include some cost/benefit figures so that the effect of maintenance can be readily seen and understood by those responsible for paying the bills. Fuel and maintenance bills should be paid from the same budget so that the effect of one on the other can be evaluated realistically.

9.2. Management

Maintenance often suffers from being designated by the disinterested to the insufficiently qualified or powerful. As a result, preventative maintenance is often neglected and eventually reduced to running repairs. The worst (but all too common) situations found were where maintenance and general building management had been assigned to a member of middle management who probably had other duties, and the person with hands-on experience either was not senior enough to have much influence, or only appeared on site every month or so.

The case studies illustrated how a well managed building with a motivated and well informed workforce is needed to supplement a good design for the building to be successful. Problems are resolved promptly before they become a major issue, and the staff respond well accordingly.

Sub-metering is an important management tool in monitoring and evaluating building performance and changes. Metering equipment should be installed where it is appropriate and will be used. Meters could be located in the entrance hall or canteen to show how well the building is being run.

The use and occupancy of a building is likely to change many times during its lifetime. It is impractical and uneconomic to provide too much long-term flexibility. In the medium-term however, say the lifetime of the services, it should be possible to accommodate a limited range of changes with minimum disturbance such as different office layouts and partitions, occupancy densities, etc.

At present there is not much incentive to reduce energy usage in speculative office developments, particularly if capital costs (or lettable areas) are affected, and if the savings are not reflected in higher rents. The landlord/tenant split of responsibilities can also pose problems. The people in charge of plant etc in a multi-occupancy building generally have no incentive to reduce running costs and little understanding of tenants' needs. Some developers have felt that there is a marketing advantage if energy costs are lower, but they are in the minority given the insignificance of energy costs when compared with property rental and staff costs.

9.3. Controls

The idea of control in a building refers not only to how to drive and configure the automatically controlled systems becoming more common in buildings, but also includes such simple matters as windows and office layout. While this is covered in greater depth in the BUS study of user-occupant controls, it is worth mentioning here.

Local control problems are generally more prevalent in open-plan areas than in cellular offices where a small number of people can make choices relatively easier. The case studies provided many examples of how open-plan lighting was nearly always all on, whereas cellular lighting was off more often than not.

Good management becomes more difficult the more complex the building is. This unfortunately can mean that complex technical means aimed to increase comfort or reduce energy consumption can actually bring about a situation where the management loses control of the building, and comfort levels actually reduce or energy use increases. It is therefore better to do a few well-chosen things well than to smother a building with technology in the belief that every additional measure will help. Preferred comfort conditions vary between individuals, and it is not always possible to keep everybody happy regardless of the efforts made.

If controls (both manual and automatic) are to succeed in open-plan areas, they must follow a few rules.

- Controls should be territorial, ie their operation should influence the space occupied by one person if possible, and should be near the area that they control.
- They should be intuitive. The new generation of phone-operated systems require an operation which is not as obvious as reaching for a light switch, a window, or a thermostat. There should also be some obvious indication that control action has been initiated.
- Controls should be placed in obvious places, and not where they will be obscured by furnishings or difficult to reach. Desks should not be put in unexpected or unsuitable locations, or where they can obscure controls.
- Systems should be robust and capable of being easily re-configured, when office layouts change for instance.
- Automatic systems should have simple overrides.
- Management should understand how the systems interact, the scope for using them in parallel, and how to avoid possible conflicts.
- Where possible, the default state should be the low-energy state, and systems should aim to go off automatically when there seems to be no further need for them.

10. CASE STUDY BUILDINGS

This section summarises information on the 12 buildings monitored on the 10 chosen sites. Further information on the buildings is obtainable from the Building Research Establishment.

Many of the buildings had previously been investigated in other research projects, others were thought to be good examples of non-air-conditioned design, and some were deliberately chosen as they were thought to suffer from summer overheating.

The buildings all had openable windows; some of them were also mixed-mode in design.

In some of the buildings, the monitoring was performed in tandem with user interviews and surveys. The monitoring equipment was left in most of the buildings until late October. This provided the opportunity to gather information on the degree of control of the heating systems. While recommended temperatures are around 21°C, offices generally seem to be at around 24°C. This is actually illegal.

Salient information about the buildings is given in summary tables in Appendix A. Graphs showing the temperatures reached in each building and modelled temperatures for external conditions of 20±5°C are also given in Appendix B.

The mixed-mode buildings studied all had parallel/concurrent systems; other definitions of mixed-mode are given in 6.3. The contingency-planned building G is naturally ventilated at present.

10.1. Monitoring results for Type 1 buildings; naturally ventilated cellular offices

These Type 1 buildings showed generally lower lighting usage than open-plan offices, and the windows were used more. There was often a lack of air movement resulting from single-sided ventilation, and the glazed areas were quite high in these particular buildings. The window technology in particular left a lot to be desired. In the first building the area on the north side of the building actually had the original windows which provided more operational choice and better ventilation than those installed in the refurbishment.

10.1.1. *Building L*

Building L was a refurbishment project carried out in the early 1980s for a building occupier in central London. There are south-west facing offices with a 40% glazed area and natural ventilation via tall and narrow (approx. 1.4 m x 350 mm) tilt and turn opaque panels. Some offices have been retro-fitted with tinted glazing film to reduce solar gains.

The construction is medium weight; with plasterboard ceilings, and solid floors and partitions. The installed lighting loads are 15 Wm^{-2} to 28 Wm^{-2}, with higher installed loads and usage in the 2-person offices. Equipment gains are 10 Wm^{-2} to 14 Wm^{-2}. The computers are networked and are therefore on for most of the time, despite management efforts, resulting in a load of 7.5 m^2/person to 10 m^2/person.

The vent was intended to provide secure night ventilation, but is now closed at night due to security worries. It is seen by occupants as depriving them of more daylight and/or view, rather than reducing solar gains, and its area is too small to achieve good air movement on still days.

The peak temperatures recorded were quite low (peak 0.7°C below ambient), but direct solar radiation and lack of air movement make the building somewhat unpopular with the occupants. However those people interviewed seemed to prefer the building to an air-conditioned one (including some people who had previously worked in air-conditioned offices).

10.1.2. *Building R*

10.1.2.1. *Main buildings*

Building R's 1970s main buildings have a 60% glazed area, comprising mostly 1- and 2-person cellular offices. They have a history of overheating in the summer. It was a green field site with the buildings commissioned by the occupant.

The buildings are of heavyweight construction, with an installed lighting load of 17 Wm^{-2} to 23 Wm^{-2}. There are higher installed loads and lower usages in the 1-person offices. Equipment and occupancy gains are variable.

The internal shading, as provided by blinds and curtains, conflicts with the centre pivot windows. Pilot modifications have been made to the glazing system, including hopper windows at high and low levels and a reduction of the glazing area by blank panels or an external fixed micro-louvre system.

These measures reduced peak temperatures by 1°C to 3°C (to 26°C to 28°C) for external conditions of 20±5°C, but were often not popular. The hopper windows were liked, despite poor construction, detailing and control. User surveys showed that many people would tolerate overheating to keep a nice view. The hoppers were especially difficult to procure; hardly any companies seemed interested in their design or manufacture. The specially made design as installed did not meet the specification, with important shortcomings, notably in control and air leakage.

10.1.2.2. *Mansard areas*

Additional lightweight mansard top floors were added as a low-cost extension. The office use was similar to that of the main areas, although more plan areas were provided.

The double glazed Velux windows had captive internal venetian blinds. Some occupants left the windows ajar at night for night ventilation. The large expanse of black tiled roof gave high solar fabric gains which passed through the thin structure as well as pre-heating ventilation air.

Some cellular offices still had switching patterns left over from when the area was an open-plan office. The lighting in a number of rooms was controlled by a gridswitch located at the ends of a corridor.

The temperatures reached 35°C in some cases. These areas suffered from major design problems. Some, such as light switching, were easily solved. Others were inherent in the type of construction.

10.2. Monitoring results for Type 2 buildings; naturally ventilated open plan

The main differences expected between these Type 2 buildings and the Type 1 offices were the increase in lighting use, decrease in window use, and better cross-ventilation. However, the lighting control systems installed in some of them, especially the remote infra-red control type, reduced lighting use markedly. In some buildings a decrease in window use, owing to the open-plan mentality, reduced air movement and ventilation rates. There were incidences of breakdowns in the management/occupant control interfaces in these buildings, particularly with regard to ventilation and light switching.

10.2.1. *Building G*

Building G has a three-storey, square plan constructed around a central courtyard. The building consists of mostly open-plan office space with a suspended ceiling and raised floor. The building was completed in Autumn 1991. The occupant and a local developer co-developed the building by a roundabout on the by-pass of a coastal town.

The building has a 50% glazed area (continuous and all openable) with deep overhangs to reduce solar gains. Internal blinds have been added recently but have not yet been used unnecessarily due to good management. The projected top-hung, reversible, triple-glazed windows have a number of secure settings, and can also be opened fully without impinging on the internal space.

The office is very uncluttered, allowing good cross-ventilation. The lighting system combines efficient fittings (installed load 12 Wm^{-2}) with a dimmable remote control system, and central 'off' and daylight linking. There is separate low energy lighting for notional circulation corridors. The system is very popular and accordingly has a low lighting energy use (estimated at a summertime average of 3 Wm^{-2} to 5 Wm^{-2}). This is aided by the high incidence of VDU-based work (mainly black-on-white screens) and the young workforce. Equipment gains are 12 Wm^{-2} to 15 Wm^{-2}, with an occupancy density of 9 m^2/person to 12 m^2/person.

The average temperatures attained in summer were commendably low, with a maximum internal temperature of 27°C when the external peak was 27°C. The building was very popular with occupants. There could be potential management problems as the facilities manager has left and the new management may not be capable of getting the most out of the building. However, the building is fairly simple and straightforward anyway.

10.2.2. *Building I*

Building I was an early 1980s building designed to make use of natural light and cross-ventilation, and having high thermal mass. It was commissioned by the occupant on a green field rural site. The building won an award in 1986 for services design.

The building has high ceilings with a mezzanine area of offices. The office space is mostly open-plan, but there is increasing cellularisation. The glazed area is approximately 30%, with internal fabric blinds.

The lighting gains are 14 Wm^{-2}, but the lights are switched in blocks of around 80 fittings and so tend to be on all day. The facility for local switching is not used. Equipment gains are 4 Wm^{-2} with an occupancy density of 10 m^2/person.

Cross-ventilation is impeded by the increasing partitioning of cellular offices on the mezzanine floor. The sash windows are difficult to operate due to the thin section frames and furniture sometimes having been placed in front of them.

Partitioning and worries about security and rain ingress inhibit effective night ventilation.

The CHP unit and generator for the pumps, which were intended to provide waste heat and electricity to the building, are now not used due to the fragmentation of the company during privatisation.

Average internal temperatures were quite high with a peak 1°C above an external peak of 26.5°C; the greatest problems being the lack of air movement and night ventilation. Middle management were not too interested in fine tuning or in making any investment (in finance or effort) to improve the building performance.

10.2.3. *Building J*

Building J is a 1980s two-storey block commissioned by the occupant. It is an open plan heavyweight building with acoustic panels inset into a coffered ceiling to combine acoustic deadening with the heavy ceiling structure.

There is a 50% glazed area provided by centre pivot windows with external fixed window head louvres and automatic roller blinds at their outermost edge (set at approximately 1 m from the façade).

The windows are difficult to reach, the trickle vents which were fitted for night ventilation have insufficient capacity and their operation is not understood by occupants. The installed lighting load is 17 Wm^{-2}. Lighting is provided by discharge uplighters, with controls which are generally overridden because of run-up times and the poor positioning of lights. The lighting system is not popular. Equipment gains are 15 Wm^{-2}, with an occupancy density of 14 m^2/person (50% higher density than design).

This extra occupancy and associated clutter reduces air movement, outside awareness, and illuminance levels. There is poor cross vent owing to the small courtyard and nearby wall, as well as window operation problems.

The internal temperature was stable but too high, peaking at 25.5°C when the external peak was 20.5°C.

10.2.4. *Building K*

This is a 1970s six-storey 'slab' tower block commissioned by the occupant, located on the same site as building J. It has a 60% glazed area and is a medium-weight structure.

A re-cladding scheme incorporated automatically controlled external translucent blinds. Internal curtains are also available for glare control. The installed lighting load was 14 Wm^{-2}, with in-use loads of about 5 Wm^{-2} given the high IT use and large amounts of daylight. There was partial presence detection control of the corridor lighting; with block switching of the lights in the main areas. Equipment gains are 19.7 Wm^{-2}, with 10% to 15% left on at night. The occupancy density is 14 m^2/person.

There is good cross-ventilation. Internal temperatures are high and with a large range. The peak was 25.5°C with external conditions of 17±3.5°C. This was perceived as being more comfortable than building J due to better air movement, better lighting, fewer internal screens, and a better external view.

10.2.5. *Building Q*

This award-winning building, on the outskirts of a large city, was completed in 1990. It was commissioned by the occupant to a pan-European corporate standard.

It is similar in many respects to building G, (square plan around central courtyard, suspended ceiling, raised floor, lighting control system) but not as successful. The lighting system is not as powerful and has no central control or dimming facility, but it is almost as effective.

The building has a 29% glazed area, of which only 1/6 is openable tilt and turn windows. Internal shading is provided by fabric blinds. The installed lighting load is 11 Wm^{-2}, with an in-use load of 3 Wm^{-2} to 6 Wm^{-2}. LG3 category 1 downlighters with remote control switching have been installed in blocks of four giving a gloomy feel to the building. Equipment loads are 16 Wm^{-2} (office) to 25 Wm^{-2} (computer area), with an occupancy density of 10 m^2/person (office area).

Both the cross-ventilation and the view are impeded by a cluttered and partitioned office (fitted out, including lighting by the client). The small opening window areas impede ventilation. The interior environment is rather oppressive. The amount and height of furniture is now being reduced to increase the ventilation rate and avoid 'land-locked' areas.

The corporate feel and management style is rather regimented. The telephone and communications room dumps all of its gains into an office area. These types of detail were generally poor.

The internal temperatures are more stable than might be expected, peaking at 26°C when the external peak was also 26°C. The building was not too popular with the occupants due to the oppressive feel and lack of air movement.

10.3. Monitoring results for Type 2-3 hybrids; mixed-mode standard

These buildings can provide a safety valve which is not present in Type 1 and 2 buildings, as any lack of air movement and night ventilation can theoretically be taken care of by a mechanical system. The system can also ensure ventilation when the blinds are down. The cooling effect available in these buildings can also be considerable if the use of the building fabric is optimised.

10.3.1. *Building O*

This is a superficially lightweight building with an underfloor supply of air utilising the thermal mass of slab and/or ground. The extract is via the ceiling. It has a 21% glazed area provided by tilt-and-turn windows. The top floor had 50% glazing with deep overhangs, though the effect of this was not studied.

This building was designed by the occupants and is situated on a small business park on the outskirts of a new town. It is an all-electric building, having off-peak heating with daytime top-up, and a runaround coil for heat recovery on a two-speed, full fresh air system.

The installed lighting load is 14 Wm^{-2}, with typically 70% of the lighting switched on. There is a remote control lighting control system with daylight linking and central 'off' commands, but the small windows mean that the amount of daylight received is limited. Equipment loads are 4 Wm^{-2} with an occupancy density of 12.3 m^2/person.

The use of the slab offers good stability, probably as air recirculates in the floor compartments before entering the room. The first floor was generally 1°C to 2°C warmer than the ground floor. This created slight problems in keeping both floors at suitable conditions as the control seemed to be optimised with respect to the ground floor. Temperatures were stable and low in the ground floor office; 1°C to 2°C lower than external peak of 26.5°C, with the first floor 2°C higher.

The BMS user interface is primitive, requiring an intimate knowledge of the system. Although this may be appropriate for an engineering company with on-site expertise, only one person knows how to operate the system at present and this could present problems in the future. The level of intervention and systems management needed is probably too high for an average building of this size.

10.3.2. *Building P*

Building P is a 1970s lightweight building, 60% single glazed by openable metal sash windows. It faces east and west on the same site as building O. There is a background mechanical ventilation system having ceiling supply and extract.

It has a similar lighting system to that in building O installed with a suspended ceiling which obscures the previously exposed slab. This has reduced the thermal mass considerably. Equipment gains are 3.7 Wm^{-2}, with an occupancy density of 18 m^2/person.

The partitioning sometimes causes problems with the positioning of the vents. The internal venetian blinds offset some solar gains but obstruct ventilation. The temperatures are higher than building O, with the ground floor at 26°C to 28°C internal peak, when the external temperature is 21±5°C.

10.4. Monitoring results for Type 2-4 hybrids; mixed-mode prestige

These buildings should be comparable in 'feel' with major corporate headquarters buildings. That they achieve this feeling indicates that air-conditioning should not be the automatic choice of a company, whatever their perceived status. These buildings generally had greater ancillary facilities, eg catering and swimming pools, and provided, in two cases out of three, very good working conditions for their occupants. In the third case, some minor modifications would increase comfort levels considerably.

10.4.1. *Building S*

This is a large head office with high ceilings and the use of thermal mass. It is located on a green field site on the outskirts of a small town and was commissioned by the occupants.

It has a 30% glazed area, with centre pivoted windows with high level hoppers for deep or night ventilation. The installed lighting gains are 14 Wm^{-2} with in-use loads of 7 Wm^{-2}. The system is centrally controlled with local switching.

Equipment gains are 16 Wm^{-2}, with an occupancy density of 9 m^2/person.

The central AHU supplies the office area with 2 ach of fresh/recirculated air via high level punkah louvres.

The internal temperatures are very stable and commendably low, peaking at 25.5°C with an external temperature of 28.1°C. It is interesting to note that this is without the direct use of building mass (eg floor voids).

10.4.2. *Building T*

This is a simple, single-storey prestige office building on a green field site in a rural environment, with single aspect offices and an open-plan central office core area. The building was commissioned by the occupants.

The central AHUs provide mechanical ventilation at 5 ach to 10 ach via the floor void. The perimeter offices are also ventilated via sliding patio doors and small casement windows.

The floor void is not used as well as at building O. Temperature reductions of up to 1°C occur along the void. This reduced effect is probably due to the different balance between heat transfer and the time of residence of the air in the void.

The installed lighting loads are 16 Wm^{-2} in the core areas, and 26 Wm^{-2} in the cellular offices. These high loads are caused by a lack of control in the design process and occupant requirements for an arbitrary standard of 600 lux where it is not necessary. The core lighting was always on, the cellular lighting had about 70% usage.

Equipment gains are 6 Wm^{-2}, however the occupancy density is only about 25 m^2/person owing to the large cellular offices and the amount of circulation space. There was some overheating of the central core areas. Monitoring revealed high lighting loads with poor controls and under-performance of the night time floor cooling operation. Since then local light switching has been installed and the building energy management system (BEMS) settings have been adjusted. There have also been problems with obstructed dampers and heating valves 'letting by'. There is a lack of feedback alerting management to mechanical problems like this.

Temperatures were not as stable as expected. The peak was 27.8°C with an external peak of 27.9°C. Better use of thermal mass and reduction of gains might reduce this by 3°C.

10.4.3. *Building U*

This is a prestigious HQ building in a green field site on the outskirts of a town and incorporates the extensive use of passive thermal mass. The building was commissioned by the occupant.

The installed lighting load is 19 Wm^{-2} for lighting levels of 370 lux with metal halide uplighters. The central control system with limited local overrides results in actual usage of 9.5 Wm^{-2} in summer. Office equipment loads are 14 Wm^{-2} with an occupant density of 10 m^2 per person. The central AHUs provide tempered air for local chilling/heating by fan-coil units which are mounted under tilt-and-turn windows. The floor void is used as a return air plenum.

The BEMS has intelligent outstations. The operation of the air handling system has been changed recently. Full fresh air has been enabled and the night time ventilation strategy operated. The BEMS has had problems coping with this, due to a lack of variables at an outstation. To avoid expensive alterations the modifications have been carried out by hand by disconnecting dampers and turning boilers off manually every night to stop the plant triggering them. Such problems with ostensibly flexible control may well be widespread. The condensation limit has still turned off the plant during the night vent program.

Temperatures were very stable (as might be expected due to the coolth stored in such a massive building), the peak was 25°C with an external temperature of 26°C. The effect of night venting and full fresh air was difficult to ascertain, as the complexity of the building means that these techniques simply result in a lower demand for cooling.

10.5 Comparison of similar buildings

10.5.1. *Building G vs building Q*

Building G and building Q are quite similar, in terms of structure, gains, and lighting system. Their occupants' reactions were markedly different but they gave similar monitoring results. The buildings are summarised in table 10.1. Whereas building G was very popular with its occupants, at building Q there was competition between groups of occupants for installation of the monitoring equipment in their vicinity to show how uncomfortable the summertime temperatures were.

The different reactions to the building environments are thought to occur because of the following.

i Cross-ventilation and therefore air movement is poor at building Q, because of the low opening window position and the large amount of furniture screens. At building G, the area of opening windows is greater, and cross-ventilation is not obstructed. The window-to-window distance is also less.

ii. The furniture also helps to make building Q feel gloomy and oppressive, where building G feels slight and airy. Many occupants of building Q are surrounded by furniture and have no view of the windows. The respective impressions of gloominess and brightness are also reinforced by the lighting.

iii The lack of external shading at building Q means that the blinds have to be lowered more often than at building G, further reducing ventilation and view.

iv The management style at building Q is more hierarchical and rigid than at building G, which may encourage occupants to grumble more to an outsider. The formal dress code at building Q limits the degree to which occupants can vary their clothing to suit the weather; at building G, staff can wear (within reason) what they like.

10.5.2 Building O vs building T

Building O and building T both utilise an underfloor ventilation system to use the thermal mass. This gives both buildings thermal stability, and means that while the occupied spaces superficially have a low thermal mass (building O more so than building T), they actually behave as though they are heavy buildings.

At building O, temperatures were around 23.6±1.2°C on the ground floor, at building T corresponding temperatures were around 24±3°C. The reasons for this are as follows.

i The underfloor ventilation has less of a stabilising effect upon air temperatures at building T, reducing incoming air temperatures by a maximum of 3°C to 4°C despite the higher air flow rates, as opposed to up to 5°C at building O. This is partly due to control problems (dampers and valves) and high fan gains at building T, but may also result from floor void flow patterns and their effect upon heat transfer.

The perimeter offices (where most recirculation within the void may be expected) at building T had a slightly reduced flow rate, which may have reduced heat transfer coefficients in these areas. It seems that building O achieved a better balance between air movement and turbulence (which increases heat transfer coefficients) and the time of residence of the air in the void than did building T.

ii Building T had higher internal (lighting) and solar gains than building O.

iii Building O is deeper than building T and has greater partitioning which reduces cross-ventilation.

iv Building T has a larger glazed area.

Feature	Building G	Building Q
Construction	Suspended ceilings, raised floor	Suspended ceilings, raised floor
Glazed area	50% plus overhangs	30%
Internal shading	Fabric blinds	Fabric blinds
Window type	Projected, top-hung, reversible	Tilt and turn
% of glazing openable	100%	33%
Height of openable windows	Cill height to ceiling	Between 0.9 m and 1.7 m above floor level
Depth of space	12 m	15 m
Total internal gains (including people)	27 Wm^{-2}	25 Wm^{-2} to 35 Wm^{-2}
Management style and corporate culture	Young, dynamic, informal, environmentally aware	Traditional, hierarchical, somewhat impersonal
Origin of company and culture	Britain, 1970s	Germany, 19th century
Furniture	Little and low, light grey	A lot of tall and bulky dark grey furniture
Peak temperature	27°C	26°C
External temperature	20.5±6.5°C	18.5±6.5°C
Night ventilation	Possibly some	Unlikely and discouraged
Light fittings	Partly specular	Highly specular

Table 10.1 Building G vs building Q

11. CONCLUSIONS

11.1 Basic principles of non-air-conditioned buildings

Non-air-conditioned buildings rely on the fact that people are more tolerant of variations in their immediate environment if they feel that they have more control over this environment. Many factors can influence this issue; one of the most important of these is that they should be able to open windows, should they wish.

The degree to which the internal temperature can be allowed to vary is thus determined by many variables, and therefore there is no single set of environmental conditions which are the 'worst acceptable' ones for all naturally ventilated/mixed-mode buildings. Designers should note that this study found occupants who complained about overheating at temperatures as low as 24.5°C, and others who were quite happy at 28°C. Other devices should be used where possible to increase this threshold, by (for instance) good air movement, local control, internal views, external views and responsive management.

In order for these controls to function properly, they must form part of a single robust strategy, in which each control or device is not allowed to interfere with any others. The failure or disabling of any system or strategy should not interfere with the operation of the others.

The more complex the building and its systems are, the more management is required to keep things going. Good management can result in a virtuous circle, as unnecessary complexities are ironed out, the day-to-day running is prioritised, and the occupants are kept happy, which in turn increases their tolerance. By contrast, if management lose control of a building, not only is it difficult to bring it back to within the comfort envelope for that building, but the occupants will also be less tolerant of the variations in their conditions.

In order for the buildings to work properly, there are a number of other steps which must be taken. Details of how to approach these issues are given earlier in this document.

- Minimise heat gains from the sun, lighting, equipment, and occupancy (where possible) gains.
- Ensure effective ventilation of the whole building, in all seasons, and at night.
- Size thermal mass according to likely gains and ventilation strategy.
- Design for easy management and low energy default states. The best way of ensuring that management stays in control is to keep the building as simple as possible.

Utilise simple modelling procedures to assess the likely effect of changes to any of the factors listed.

The fit-out of the office and any future refurbishment or partitioning can clash with controls, ventilation paths, and exposed thermal mass; this should be avoided by ensuring that the fit-out is designed by, or with reference to, the building design team.

11.2 Mixed-mode design

There will always be some buildings where equipment loads are exceptionally high, or where the future use of the building is not certain. This is where mixed-mode design concepts should be used.

The mixed-mode buildings which we restudied were generally successful and popular with their occupants, and mostly maintained peak temperatures at levels which are considered satisfactory. They were also able to convey the feeling of a prestige building (buildings S, T, and U), or could be built down to a limited budget (building O). This shows that the concept of mixed-mode design can be moulded into whatever is required of it.

Extra space may have to be provided for future plant and service routes, and mechanical and natural ventilation systems should be designed so that their controls and configurations work independently of, but in conjunction with each other.

Ventilated floor voids can confer extra stability, provided that the flow patterns are optimised.

Floor grilles should be moveable without having to cut new carpet tiles. This may seem a minor point, but it can reduce the flexibility of the ventilation system, and is normally not addressed.

11.3 Design process and procurement

The main reason that most buildings are erected is to make money. There are a number of reasons why this works in favour of air-conditioned buildings.

1. Property agents have played a major role in creating the rent premium chargeable for air-conditioned space, which makes these buildings give a higher and more reliable return on investment.

2. Lending institutions want to get a return on their money, and so follow and in turn dictate the market.

3. Developers are to some extent trapped in the middle, and simply tend to enforce the arbitrary criteria (22 ± 1°C , 600 lux, etc) which the lenders have demanded.

4. In areas where land is expensive, deep buildings make best use of the land area.

5. Planners tend to dictate a plot ratio and maximum height for buildings. This in turn defines the nature of the space.

6. Narrow buildings have more perimeter per unit area.

Some of these issues can be challenged by environmental arguments, but a change in attitudes has to occur, with prospective tenants who realise that air-conditioned buildings are not only more expensive to run, but will probably be less popular with their staff. In this way, the rent premium will become lower, and the justification for installing air conditioning will be reduced.

There have been instances where the BREEAM system has been misunderstood (or misinterpreted), with a building being publicised in the press for 'having a BREEAM certificate' without indicating how well it performed in the assessment.

The initial design should be worked out with all members of the design team, including an expert on user issues and controls if possible.

Legislation will have limited potential, as restricting air-conditioning in buildings could easily result in many poor naturally ventilated buildings being erected.

The existing building stock contains a great number of bad naturally and mechanically ventilated and air-conditioned buildings. The problems in these are a combination of management, alterations over the years, poor design, and change of use. Strategic examples of how to deal with these problems (eg excessive window areas) should be publicised.

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SHEET 1	TYPE 1 (NATURALLY VENTILATED CELLULAR) BUILDINGS		TYPE 2 (NATURALLY VENTILATED OPEN-PLAN) BUILDINGS				
	BUILDING L	BUILDING R	BUILDING G	BUILDING I	BUILDING J	BUILDING K	BUILDING Q
GENERAL							
Date of completion	Early 1980s (refurbishment)	Early 1970s, extended 1980s	1991	Early 1980s	1986	Early 1970s, re-clad 1980s	1990
Total gross area (m^2)		n/a	6350	2400	4000	8150	12521
Total office area (m^2)		n/a	3000	2000	3500	4220	9000
Occupancy in monitored areas (m^2 per person)	7.5-10	7-18	9.4 (general area) 12.3 (computer area)	10	14	14	10
CONSTRUCTION							
Heavy or light materials	Light	Heavy (main)	Light; suspended	Heavy	High; semi-exposed coffered ceiling	Medium; solid floors, suspended ceilings	Light
Where is accessible mass?	Floors	Solid floors (all) Exposed soffit and some solid walls (main floors)	Walls	Solid floors, duripanel and coffered ceilings	Ceiling, walls	Floors, external walls	Walls
Total available admittance per m^2 floor area (including furniture) (WK^{-1})	10-12	7-20	9	15-20	12	9	9
DIMENSIONS (m)							
Internal depth (double or single aspect)	5 to 7 (single) 15 (double)	4,5-6 (single)	12	10 (double) 5 (single)	10 (double)	15 (double)	15 (double)
Floor-ceiling height	2.6	2.7 (main) 3.1 (mansard)	2.7	2.8-5	2.7	2.7	2.7
GLAZING							
Main façades face?	SW	WSW, ENE, SSE, NNW	N, S, E, W	N, S, E, W	NE, SW, SE, NW	NE, SW	N, S, E, W
Glazed area; main walls	40%	60% (main) 30% (mansard)	50%	30%	30%	60%	29%
Flank walls	0%	0%		0%			
Protection	Internal venetian blinds, tall buildings nearby	Internal curtains and venetian blinds (main), frame fixed venetian blinds (mansard)	Deep overhangs, internal fabric blinds	Internal fabric blinds	External window head louvres and blinds	SW side; Internal curtains, external automatic blinds	Internal blinds
LIGHTING							
Type	Fluorescent, uplighters (cell)	Surface fluorescent	Recessed dimmable HF fluorescent	Surface fluorescent	Mercury fluorescent uplighters	Surface fluorescent	Recessed HF fluorescent

SHEET 2	TYPE 1 (NATURALLY VENTILATED CELLULAR) BUILDINGS		TYPE 2 (NATURALLY VENTILATED OPEN-PLAN) BUILDINGS				
	BUILDING L	BUILDING R	BUILDING G	BUILDING I	BUILDING J	BUILDING K	BUILDING Q
Lighting level (lux)	250-450 (cellular) 350 (open plan)	400-500	500 max	350-400 (est.)	300	500-600	500
Installed power (Wm^2)	15-28 (cellular) 20 (open plan)	17-23	12	11	19	14	11
Lighting controls switching	Cellular offices switched separately	Reset switches in some deeper rooms; some mansard rooms switched together	Remote dimmable controls for pairs of fittings, daylight linking, auto off at lunch and in evening	Switched in banks in open plan areas	Nominal daylight linking rather ineffective	Switched in zones, auto corridor switching	Remote control operating 4 No. fittings
% of lights on in summer	0-100 (cellular) 60 (open plan)	10-90	35-50	100	90	40	20-50%
Actual lighting load (Wm^2)	0-28 (cellular) 12 (open plan)	2.3-15	3-5	11	15	3.5	2-5.5
EQUIPMENT GAINS (Wm^2)							
Daytime	10-14	2-15	12-15	4	15	20	16-25
Night-time	0	0	0-3	0	2	3	0-5
VENTILATION							
Window type	Tilt and turn flap	Centre pivot; hoppers added at low and high level in main areas as part of study	Projected top hung with locking positions	Sash (in walls) Bottom and top hung hoppers (high level)	Centre pivot about horizontal axis	Centre pivot about horizontal axis	0.9 m square tilt and turn (33% of glazed area)
Cross-vent	Poor	n/a	V. Good	Originally good now poor	Poor	Not bad	Moderate to poor
Draughts	Variable	OK	Problematical in winter?	OK	OK	Problematical in winter?	Probably OK
Window operation	OK	Good	Easy and quick	Difficult	Sometimes clashes with furniture	OK	OK
TEMPERATURES (°C)							
Internal air temp	24.5±1.8	26.5±2.5 (control) 24.7±2 (modified) 28.2±2.5 (mansard)	24±2.5	25.5±2	24.3±1.2	23.5±2	24.5±1.5
External conditions	20.6±6.4	20.2±5	20.5±6.5	22±4	17±3.5	17±3.5	18.7±7.2
ENERGY USE (kWh^2)							
Gas	n/a	n/a	n/a	n/a	n/a	n/a	175
Electricity	n/a	n/a	n/a	n/a	127	n/a	90

SHEET 1	TYPE 2-3-4 (MIXED-MODE) BUILDINGS				
	BUILDING O	BUILDING P	BUILDING S	BUILDING T	BUILDING U
GENERAL					
Date of completion	1989	1970s	1983	1990	1987
Total gross area (m^2)	1433	1500	14400	8500	17820
Total office area (m^2)	1152	1200	7000	4500	9900
Occupancy in monitored areas (m^2 per person)	18	18	9	25	10
CONSTRUCTION					
Heavy or light?	Light; suspended ceilings raised floors	Light; suspended ceilings	Heavy	Heavy	Heavy
Where is accessible mass?	Walls, slabs via vent ducts	Solid floors, walls	Exposed soffits and walls	Exposed soffits and floor void	Exposed soffits and some walls
Total available admittance per m^2 floor area (including furniture) (WK^1)	8	8	14	8-12	14
DIMENSIONS/m					
Internal depth (double or single aspect)	15.5 (double)	15	14.8 (double)	5.2 (single)	12 (double)
Floor-ceiling height	2.7	2.7	3.6	2.9	3.0
GLAZING					
Main façades face?	N, S	E, W	SSE, NNW	N and S	N-NW and S-SE (curved)
Glazed area; main walls	21% (ave)	60%	30%	74%	30%
Flank walls	0%		0%	0%	
Protection	Overhangs on top floor, tinted glazing, frame mounted roller blinds	Internal venetian blinds	Overhangs and internal mid-panel/vertical blinds on S side	Internal venetian blinds and external planters	Mid-pane Venetian blinds
LIGHTING					
Type	Recessed HF fluorescent	Recessed HF fluorescent	Suspended fluorescent up and downlighters	Tubular fluorescent	Halide uplighters
Lighting level (lux)	600	600	350	400-600	370
Installed load (Wm^2)	14	14	14	16-26	19
Lighting control/switching	Remote control for groups 2-4 fittings, daylight linking, auto off at lunch and in evening	Remote control for groups 2-4 fittings, daylight linking, auto off at lunch and in evening	Some locally by switches; auto off at lunch and night	Local switches in cellular offices	Locally switched, central 'off' at night
Typical % of lights on	70	90	50	80-100	50

SHEET 2	TYPE 2-3-4 (MIXED-MODE) BUILDINGS				
	BUILDING O	BUILDING P	BUILDING S	BUILDING T	BUILDING U
Actual lighting load (Wm^2)	10	12.5	7	16-18	9.5
EQUIPMENT GAINS (Wm^2)					
Daytime	4.5	3.7	16	6	14
Night-time	0.5	0.5	2	1	3
VENTILATION					
Type	Natural and mechanical	Natural and mechanical	Natural and mechanical	Natural and mechanical	Natural and mechanical with mechanical cooling
Window type	Tilt and turn	Sash	Centre pivot, high level hoppers	Sliding door plus small casement	Tilt and turn
Cross-vent	Moderate	Moderate	OK	OK	OK
Draughts	Should be OK	Possibly poor in winter	Minimal	Not bad	Minimal
Window operation	OK	Not easy	OK	Moderate	OK
Central plant	Full fresh air, heat recovery	Recirculation/fresh air	Recirculation/fresh air	Recirculation/fresh air	tempered fresh air
Air distribution	Via floor plenum to	High level grilles	Punkah louvres at high level	Via floor plenum to swirl diffusers with transfer fans	Fan coils under window and in floor
Recirculation	No	Yes	Determined by CO_2 sensor	Yes	50% (see study)
ACH	2 or 6	?	2 to 4	4.5 (cellular) – 10 (open plan)	1.2
Night cooling	As part of this study	No, could be done	Adopted for study	Night circulation	Adopted for study
Control	Primitive BEMS	?	BEMS	BEMS	BEMS
TEMPERATURES (°C)					
Internal air temp	23.6±1.2 (ground) 25.2±1.4 (1st)	24.5±1.8	23.7±1.8	24.9±2.9	24.3±0.7
External conditions	19.9±6.4	19.9±6.4	21.5±6.6	19.9±8	18.7±7.3
ENERGY USE ($kWhm^2$) (excl. computer suite)					
Gas	0	n/a	118*	114*	99.5
Electricity	125	n/a	45*	82*	94.5

* not including swimming pool and covering for whole site

APPENDIX B Graphs of actual and predicted temperatures in monitored buildings.

This appendix includes plots of actual internal and external temperatures recorded in the monitored buildings for external conditions as close as possible to 20 ± 5°C. In addition, in order to allow comparisons between the buildings, predicted internal temperatures for 20 ± 5°C external are included based on an admittance-based spreadsheet calculation.

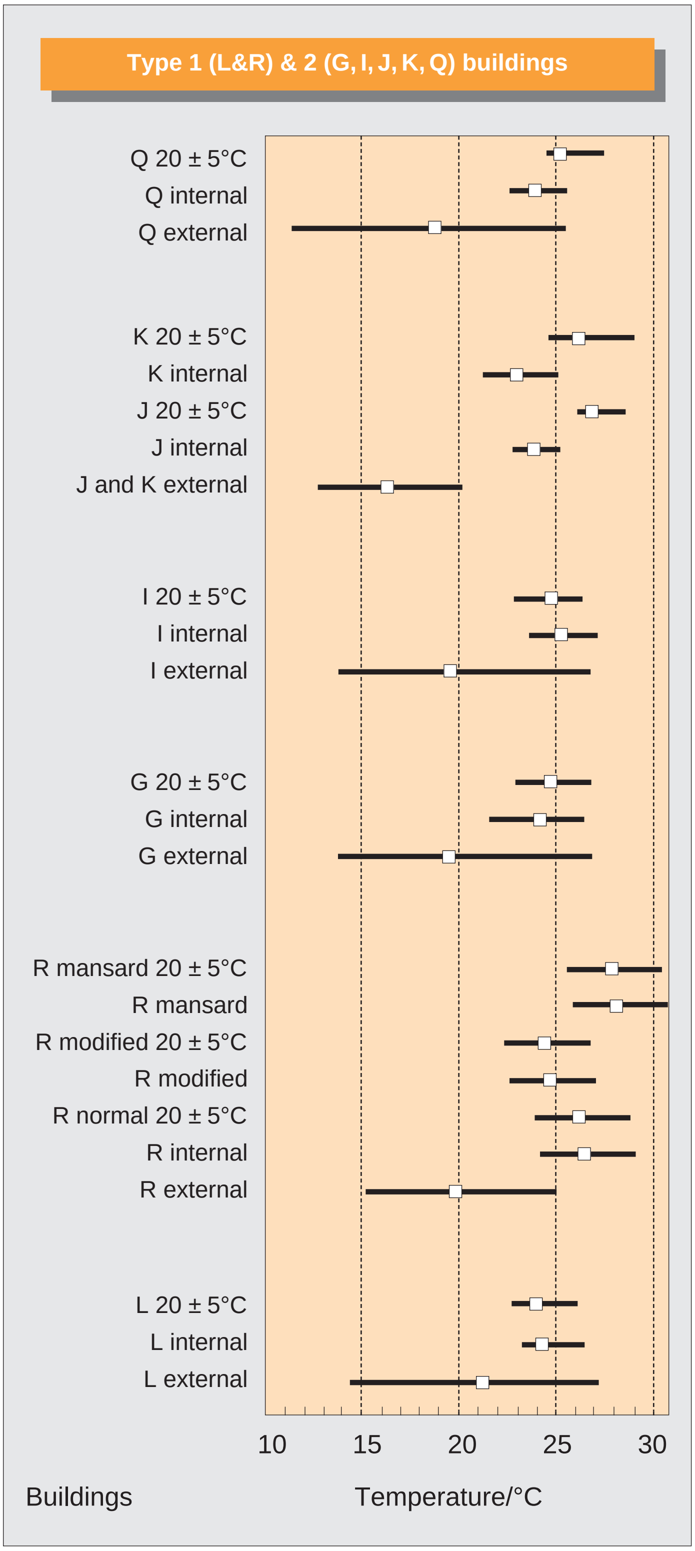

Figure B. 1. Internal and external recorded temperatures, and predicted temperatures for an external temperature of 20± 5°C, for the naturally ventilated case study buildings. (Buildings Q, K, J, I, G, R & L.) Bars show the range and mean.

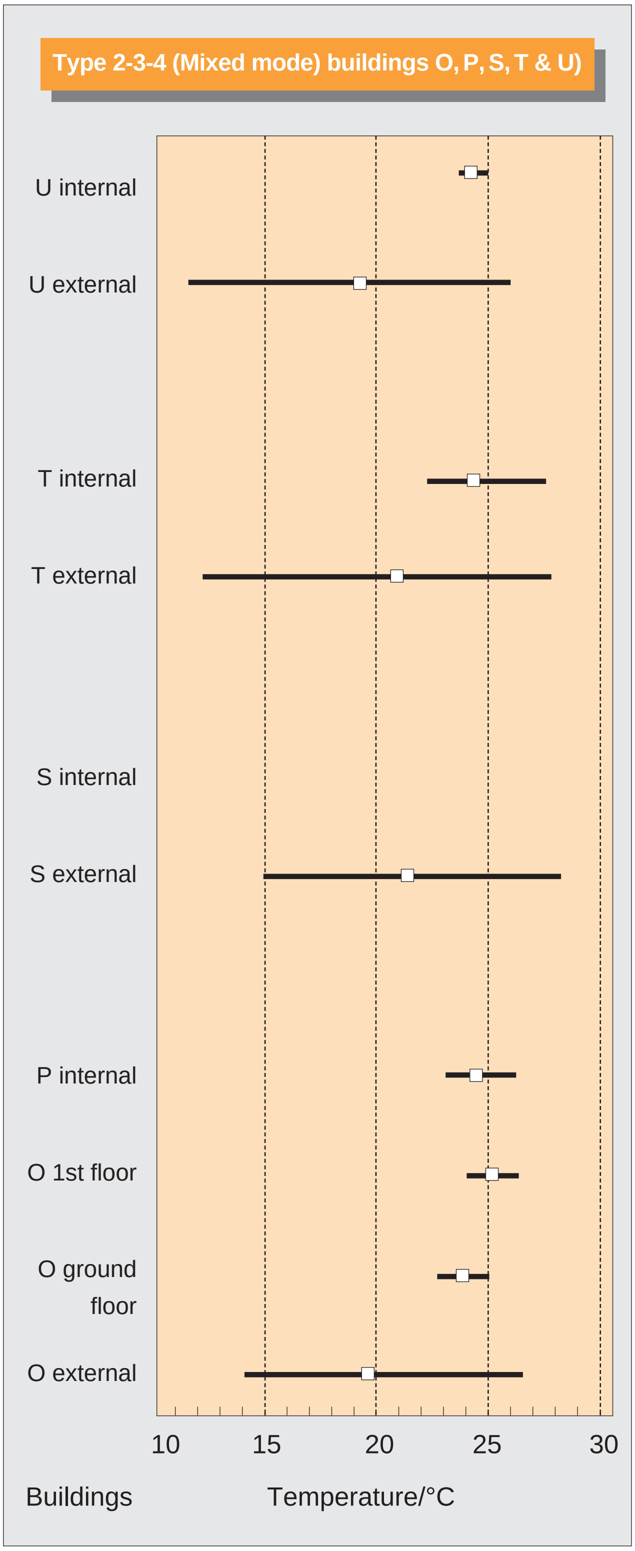

Figure B. 2. Monitored internal and external temperatures in mixed-mode buildings. (Buildings U, T, S, P & O.) Bars show the range and mean.

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