7

RETROFITTING FOR COMFORT AND INDOOR ENVIRONMENTAL QUALITY

Nick Baker

The motivation for refurbishment of and retrofit to existing buildings can be driven by a number of objectives. It could be simply to improve the energy performance, and as we now say, sustainability of the building. But if this is the case, it should always carry the constraint that the comfort of the occupants is not compromised. On the other hand, in buildings that currently deliver poor environmental quality – e.g. summer overheating, poor air quality, etc. – common defects in existing buildings, the main objective may be to improve comfort. To achieve this without incurring greater energy costs may be a secondary objective.

This chapter looks at the opportunities for achieving improved indoor environmental quality whilst carrying out measures that are known to have energy performance benefits. It is aimed at an integrated approach, where the energy performance and environmental implications are considered simultaneously.

For a rather obvious example, an over-glazed lightweight building currently overheats in summer causing serious comfort problems. Installing a state-of-the-art air-conditioning system, with a guaranteed upper temperature limit, could achieve an improvement in comfort. However, there would remain local control problems: occupants sitting near windows would still receive direct radiation and, of course, the building's energy consumption would increase significantly.

Alternatively, the facade could be remodelled, reducing glazing area, adding controllable shading devices and easily modulated openable windows. This would greatly reduce the source of the overheating and provide a personal and intuitive means of controlling fresh air and glare. It is likely that the overall satisfaction of the occupants would be greater in the second case, and almost certain that the energy consumption and maintenance costs would be much less.

ENVIRONMENTAL COMFORT

Before examining sustainable retrofit measures in detail, we will briefly review the basic principles of environmental comfort. Of the various environmental parameters that affect our comfort, temperature is probably the most critical, and one we spend most effort to control. This is probably because of the range of temperatures that the outside environment covers, on a daily and seasonal basis, often includes conditions that are not only very uncomfortable but possibly life-threatening.

Thermal comfort theory

For the latter part of the last century, the conventional wisdom was that thermal neutrality should be the target. It seemed very reasonable that people are comfortable when they are neither hot, nor cold. Experiments were carried out in climate chambers by Fanger (1970) to establish neutral temperature, and the results were used to establish international temperature standards. It was upon the perceived need to achieve these, in both the workplace and at home, that the air-conditioning industry was built.

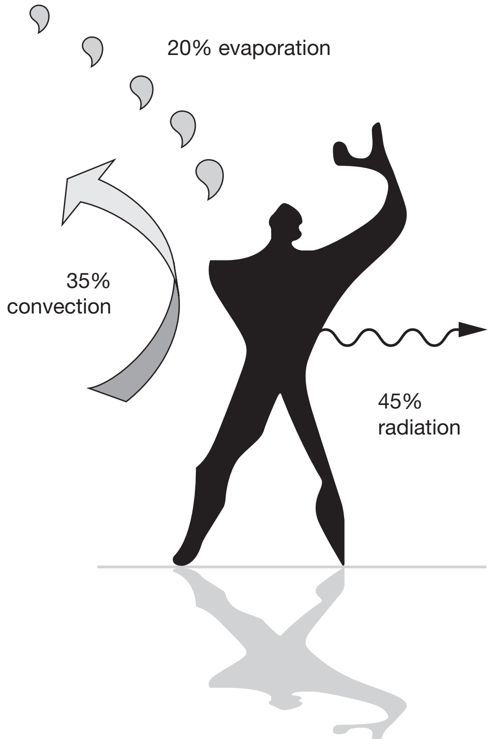
The four components of heat loss from the body, in moderate climate conditions, are shown in Figure 7.1. Conventional comfort theory assumes the comfort temperature is synonymous with neutral temperature, i.e. to be where the total heat loss exactly balances the metabolic heat gain, on an instantaneous basis. Because neutral temperatures were established in closely controlled conditions, the standards did not recognise adaptive behaviour and psychological affects, as discussed below.

Note that only 20 per cent is by evaporation. Of this about 13 per cent is by respiration and base-level diffusive evaporation. Only 7 per cent is by evaporation from moist or wet skin, and only this part is sensitive to the ambient humidity, provided it is between about 30 and 70 per cent relative humidity (RH).

In spite of this, conventional air conditioning has provided close RH control, often as close as 65 per cent +/- 10 per cent. This requires a significant amount of energy, which is completely wasted as it has no detectable effect on comfort. It is interesting that dryness of skin and eyes is often reported as a symptom of Sick Building Syndrome (discussed later), implying

Figure 7.1 The four components of heat loss from the body. Conventional comfort theory seeks to balance total heat loss with metabolic heat gain at all times

Source: N. Baker



that in spite of close RH control targets, air-conditioned buildings often deliver much too low humidities, probably due to poor maintenance and control.

It is only when in warm humid conditions, often met in the humid tropics, that humidity control, in this case dehumidification, will be justified. In these circumstances, due to high air temperature, evaporative cooling from moist skin and clothing becomes a dominant heat loss mechanism, and lowering humidity will increase comfort both from a temperature perception, and the reduction of skin wettedness.

Adaptive comfort theory

The focus on close temperature and humidity control dominated the air-conditioning design and specification for half a century. However, it was pointed out by Humphreys (1978) as early as 1978, that when comfort surveys are carried out in the home and workplace instead of comfort chambers, people report comfort over a much wider range than predicted from Fanger's heat balance theory. Humphreys also noticed that the degree to which the occupants can take adaptive action greatly influenced their satisfaction. This is illustrated in Figure 7.2, which shows a hypothetical stress response of an occupant to swings in an environmental parameter (such as temperature), away from neutral. It goes some way to explain why

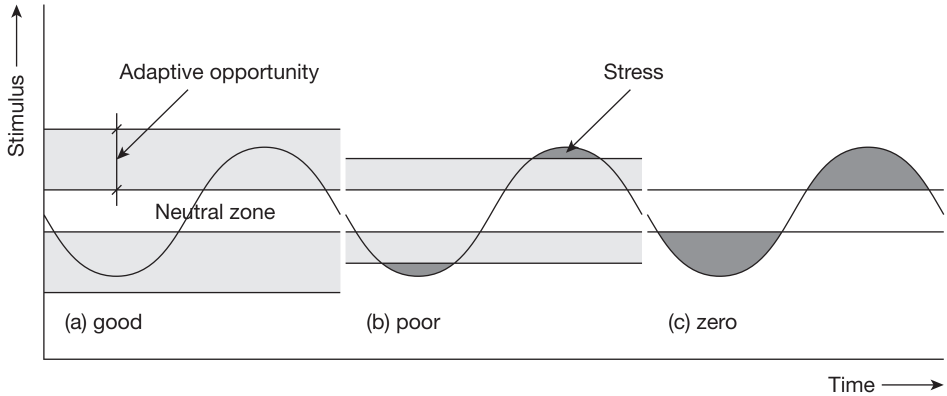


Figure 7.2 Human stress response to swings in an environmental stimulus (such as temperature) and its relation to the presence of adaptive opportunity

Source: N. Baker

there appeared to be such a discrepancy between Fanger's findings in the climate chamber, where all *adaptive opportunity* is removed, and in the real world where in most cases some adaptive opportunity exists. Later work by Guedes and Matias (2009) showed the *perceived* presence of adaptive opportunity to have a beneficial effect *even when the opportunity was not actually taken*. This suggests that there is a strong psychological component to environmental satisfaction.

Adaptive action, and the resultant benefits, extend to the control of mechanical systems. Unfortunately, many buildings are controlled by centralised management systems, which discourage or even prevent any interaction from the occupant. In other cases, controls are difficult to understand and access. Intuitive control, where the occupant carries out an action which is obvious, easy and has a rapidly responding effect (analogous to opening a window), should always be sought.

This is highly significant to the matter in hand. Only the use of energy-consuming air conditioning can guarantee close temperature standards. However, the knowledge of adaptive comfort theory, and the recognition of building elements and design that provides adaptive opportunity, can produce alternative sustainable solutions.

There are parallels in other environmental variables too. In lighting, many designers have given up on daylight as a working illumination, claiming that it was too variable and unpredictable. High levels of uniform artificial lighting became the norm, and daylight was more to do with building aesthetics than function. This was largely due to a similar misunderstanding – the notion of uniformity and neutrality. Studies by Papairi (2004) have shown that occupants prefer daylight in spite of poor illuminance geometry and intensity, provided they have some adaptive opportunity to mitigate its negative effects. It was also shown that far from ideal lighting conditions were acceptable if they we seen to be due to 'natural causes'. This phenomenon can be observed when the occupant of a room lit by the failing evening daylight, carries on a visual task such as reading, at illuminances as low as 50 lux, 17 per cent of the recommended 'standard' value, without switching the lights on.

Adaptive opportunities

Typical adaptive opportunities, some of which may be present already, and some of which may be provided by the retrofit, are listed below. Note that some relate to the personal environment – e.g. dress code – whilst others relate more to the room environment – e.g. openable windows.
Positive adaptive attributes:

- relaxed dress code;
- occupant mobility;
- access to hot/cold drink;
- openable windows;
- adjustable shading/blinds;
- desk fan or locally controlled ceiling fan;
- local heating/cooling controls;
- workstation/furniture flexibility;
- shallow plan (minimising distance from window);
- cellular rooms (reduces mutual disturbance);
- daylighting with task lighting back-up;
- good views (external and internal);
- transition spaces (e.g. balconies, atria, etc.);
- good access to outdoor areas.

Negative adaptive attributes:

- uniformity of the physical environment (temperature, lighting, colour);
- deep plan, reduced access to perimeter;
- dense occupation with restricted workstation options;
- sealed windows;
- views obstructed by fixed shading devices and screens;
- central control of mechanical services.

What does all this mean for sustainable retrofit? It is good news. It means that many retrofitting measures that are consistent with good energy performance (such as shading, natural ventilation, provision of daylighting) are also conducive to improved comfort, provided three basic principles are observed:

1 The retrofit measures, together with the existing characteristics of the building, limit the range of environmental conditions (e.g. avoiding extreme temperature swings) by passive means.

2 The retrofit measures should provide sufficient adaptive opportunities together with those already existing to cope with the environmental range.
3 Control systems should anticipate and encourage occupant intervention.

There is also another positive aspect when a number of environmental issues are addressed, that Leaman and Bordass (2007) refer to as the 'forgiveness factor'.[1] Based upon data collected in many building occupant surveys, they have found that although individual environmental parameters (e.g. temperature, air quality, lighting, etc.) may score only moderately well, when it comes to reporting the overall satisfaction with the building, occupants report a higher score, in certain types of building. These buildings are nearly always those where control is visible and intuitive, and are predominantly passive, rather than highly mechanically serviced.

This is consistent with the earlier assertion that occupants are more tolerant of non-neutral conditions when they perceive them to be due to natural causes, and we can add to that – when they understand the means by which they could mitigate them.

Healthy planning

There is a popular perception that efficient planning, especially in the workplace, means minimising the need to move away from the home base. This is particularly so in office buildings, where for decades the 'ideal' office has been one where circulation distances are minimised, and technology, such as email, has made face-to-face meetings unnecessary.

However, recent studies by Rassia *et al*. (2010) have shown that on average, occupants consume more energy moving around their workplace than at home in their leisure time. This means that workplace activity provides important exercise. If the current trend to minimise energy expenditure in the workplace could be reversed, it could help to improve fitness and reduce obesity. For example, simply standing up and walking 5 metres to a 'waste centre' uses seventeen times more metabolic energy than leaning forward and throwing a paper into the desk-side waste bin; using the stairs uses twenty-four times more metabolic energy than using the lift.

Rassia *et al*. identified the need for 'rewards' for actions that required some effort. So often it is the lift that is the luxury element and the stairs are cold and smelling of cleaning fluid (if you are lucky). But if the staircase offered fine views across the landscape, or contained art objects, or provided music, maybe people would prefer to use the stairs.

This principle could be considered when remodelling and retrofitting, and is consistent with a more holistic approach to occupant comfort and well-being.

Contact with nature

It is not uncommon to explain the role of the building as a moderator between the internal and the external environment. This is partly achieved passively, mainly by the fabric of the building, and partly by the mechanical services. Even in an urban situation, the external environment is dominated by the natural climate – e.g. sunlight, rain, wind, etc. – and may include vegetation and landscape. Thus, since the internal conditions are being to some extent driven by the natural world outside, it is important that some kind of contact to the outside can be made by the occupant. This could be purely visual, and could influence the choice of glazing design and specification, or could involve actual contact with the outside – e.g. access to courtyards, roof gardens, terraces, unheated atria, etc.

There is a growing opinion that this need relates to our genetic background. It is only relatively recently in genetic terms, (perhaps five generations), that humans have moved indoors where they now spend 95 per cent of their time. Closely related to this, there is also the belief that the exposure of occupants to high levels of daylight is essential for so-called circadian entrainment, that is the synchronising of body rhythms with the day/night cycle.

The relevance to sustainable retrofit is, first, that the existing building may already have positive attributes in this respect, which have been compromised by successive minor alterations and modifications. For example, it is not unusual for clear glazing to be treated with obscuring films, or for doors to outside spaces and terraces to be locked for security reasons. The same applies to adaptive opportunities listed earlier – windows may have been sealed, and blinds and shades removed, accessible heating controls disabled.

The considerations above point to a holistic approach to sustainable retrofit, where the whole is greater than the sum of the parts. In other words, concentrating upon a single environmental factor, such as overheating, for example, by providing air conditioning, could be less effective overall than a range of environmental measures, even if in themselves they could not achieve such close temperature control as air conditioning.

THE BUILDING FABRIC AND COMPONENTS

Thermal insulation

The motivation for thermal insulation is usually heating energy conservation. Buildings from the 1950 to 1980 period were very poorly insulated, and with the reduction of internal gains due to modern equipment and lighting, auxiliary heating is large. Significant savings in auxiliary heating energy can be made by upgrading the envelope insulation.

In terms of comfort, improvements to the envelope insulation can reduce under-heating in winter, in particular local under-heating. For example, a previous alteration may have partitioned a part of the floor plan in such a way that it included a disproportionate amount of external envelope to the installed heat input. By increasing the external envelope thermal resistance, temperature differences across internal partitions, and within spaces, will be significantly reduced.

Envelope insulation is sometimes perceived to have a deleterious effect on summer comfort due to overheating. This view has largely been prompted by simulation results, where for a given internal gain and ventilation rate, increasing the thermal insulation will indeed increase the internal temperature, for some periods of the warm season. However, if there are openable windows, it is far better to create heat loss by ventilation rather than by fabric loss, since this mode is controllable and does not have to operate during the heating season. Furthermore, other actions of the retrofit will probably reduce internal gains due to reduction in lighting loads and improved efficiency of equipment.

Envelope insulation may improve summer comfort in some circumstances. In poorly insulated buildings, overheating is often experienced in top floors due to poor roof insulation. Overheating could also be caused by a poorly insulated wall when exposed to low-angle sun. In both cases, increasing the insulation will reduce transmitted solar gain and reduce overheating. Increasing the reflectance will also reduce overheating by reflecting the solar energy away from the surface.

Thermal mass

Thermal mass has an important role in stabilising temperature and, thus, in a building without mechanical cooling, limiting peak temperatures. This has obvious implications for comfort, and makes the adoption of passive features as an alternative to air conditioning more viable.

One technical issue that is relevant to both design and comfort is the coupling of the thermal mass with the occupant, as well the source of heat gain. Figure 7.3 shows how the thermal mass in the walls and ceiling are coupled to the heat source (the sun patch), and to the occupant, by both convection and radiation. Under normal conditions, heat loss from the body by radiation is around 45 per cent, and is greater than convective and evaporative loss. Thus the radiative coupling, by direct line of sight to the mass from the body, is a positive design feature, although indirect coupling by convection is still important.

In retrofit projects, it may be possible to expose thermal mass that has hitherto been isolated by finishes, thereby meeting the criteria above. Typically, suspended ceilings and raised floors could be removed (or partially removed) to expose massive floor slabs. This could have negative effects on acoustics and noise control, which will be discussed later. Exposed massive ceilings are very effective as they are usually unobstructed allowing radiative coupling with the occupants, and convective coupling to room air.

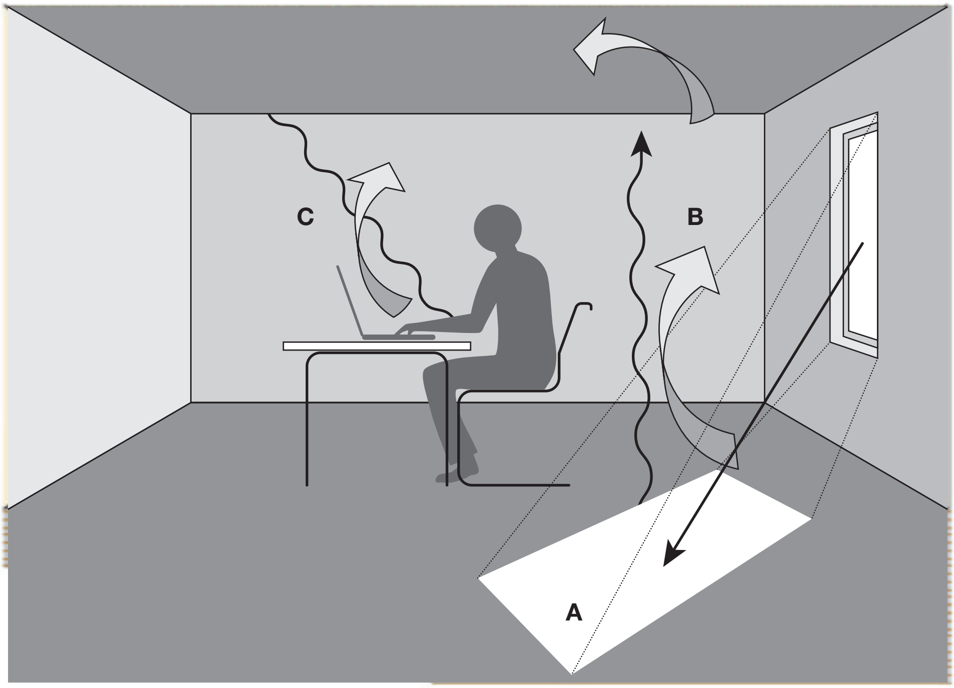


Figure 7.3 Coupling between thermal mass, sources of heat gain, and the occupants is essential for thermal mass to be effective. (A) solar radiation converted to heat at sun patch, (B) heat lost by radiation and convection to thermal mass in soffit, (C) heat lost from occupant to thermal mass

Source: N. Baker

Glazing

For highly glazed buildings (e.g. main facades with 50 per cent glazing or more), with single-glazing, losses through the glass are likely to be the largest component of fabric heat loss. Moreover, older framing systems are often leaky to air infiltration and, due to cold-bridging and their 'fin effect', can lead to a U-value significantly larger than the glass itself. Thus glazing, together with its support structure, is a common object for retrofit. Typically the facade will be reglazed using double- or triple-glazed units in thermal break framing, which can easily reduce the overall U-value from around 6.0 to 1.0 W/m^{2}K.

This has several impacts on thermal comfort. In particular, in cold conditions, the mean radiant temperature near to the glass is raised to much nearer room temperature, as indicated in Figure 7.4. This means that it does not require so much compensation from perimeter heat emitters. The cold inner surface of single-glazing also causes downdrafts, which can lead to strong vertical temperature gradients, with discomfort caused by cold feet and legs.

In summer conditions, the extra insulation value of the glass will only be of significance when there is a significant temperature difference between inside and outside. If naturally ventilated in a temperate climate,

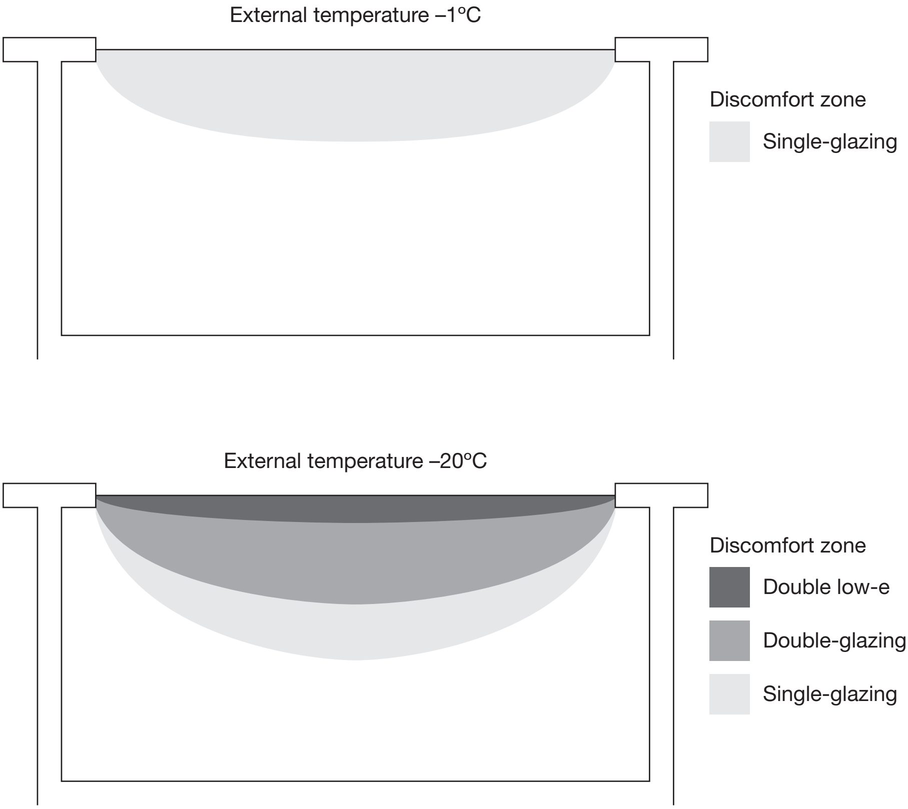


Figure 7.4 The impact of double-glazing on mean radiant temperature and comfort close to window

Source: N. Baker

with high air change rates, these differences will generally be small. The main impact will be a reduction of mean radiant temperature where the glazing is receiving direct radiation, due to the lower transmissivity of the multiple panes and the low-emissivity (low-e) coatings. However, this benefit will be modest and should not be seen as an alternative to shading devices.

Tinted and reflective glazing

Many older buildings have already been fitted, or retrofitted, with tinted or reflective glass or films. Figure 7.5 shows the mechanism of transmission and reflection for different glass types and clearly explains why tinted single-glazing is so unsuccessful. Reflective glass performs better, but consideration has to be given to the possibility of reflection of solar energy into other adjacent buildings.

Tinted or reflective glazing reduces the luminance of the outdoor scene by the value of the glazing transmission, and for transmissivities of less than 25 per cent (quite common in older installations) the reduced brightness might be significant to occupant well-being in winter.

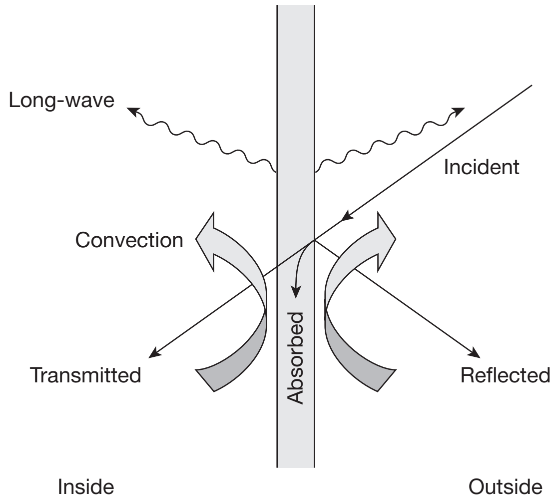


Figure 7.5 The mechanism of transmission, reflection and absorption for glass. Absorbed radiation heats up the glass. This heat is lost by long-wave radiation and convection to the outside and to the room

Source: N. Baker

Selective glazing

Modern glazing materials include selective glazing products. These have the ability to absorb and reflect the invisible part of the spectrum (mainly near infrared) that contributes to unwanted solar gain, but has no visual function. This improves the luminous efficacy of the daylight.

Glazing area

Many environmental problems are caused in part by over-glazed unshaded facades. Apart from the energy implications, these often are a direct cause of discomfort due to local thermal effects (as described above) and glare. In most cases, the motivation behind the large area of glazing is stylistic rather than functional; many studies show that for a side-lit room, areas of glazing greater than about 40 per cent of the facade have little functional benefit. This means that in a building retrofit, a reduction of glazing area and its replacement with well-insulated opaque panels should be considered. This brings comfort benefits, and also internal space use benefits. And, if the glazing requires shading, it means that the area of this costly element is reduced too.

If reduction of glazing area is being considered, three principles should be applied:

1. The upper part of the glazing contributes most to the penetration of daylight to the back of the room – the amount of reduction should take account of the depth of the room.
2. Mid-level glazing provides important distant (horizon) views – high sills cause irritating obstruction.
3. Below work-plane glazing only contributes to daylighting via external reflection from the ground and internal reflection from the ceiling, and provides near views, dependent on the floor level above the ground.

Increasing glazing may be appropriate in some cases. Deep-plan single-storey or top-floor rooms can be daylit over their whole area by roof lights. The geometry of the new roof lights and their shading should be taken into account in relation to the function of the space beneath. In many buildings, existing roof lights may have been obstructed under the misguided belief that it will solve an overheating problem. The real cause is often poor roof insulation, and the roof lights should be reinstated, with appropriate shading, as part of the upgrading of the roof.

Increasing glazing in side-lit rooms may be appropriate to improve view or daylighting. A particular case of the latter is where a suspended ceiling has been removed, making a high level of the opaque wall available for glazing; this will improve daylight penetration to the back of the room, as in Figure 7.6.

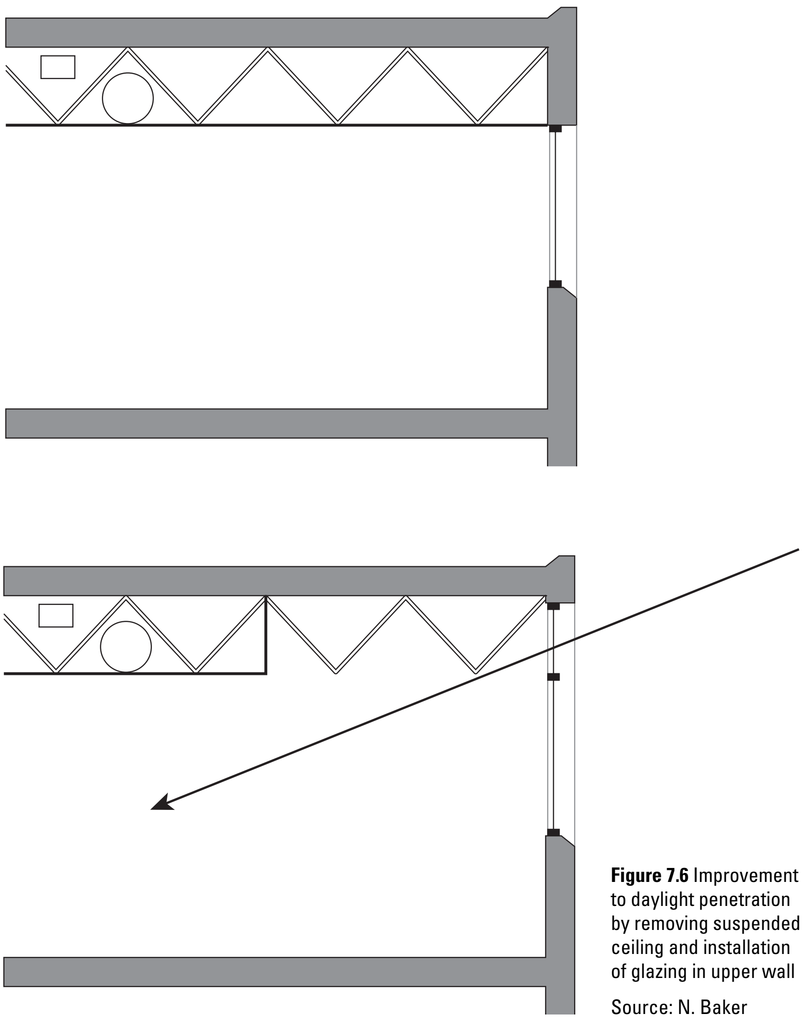


Figure 7.6 Improvement to daylight penetration by removing suspended ceiling and installation of glazing in upper wall

Source: N. Baker

An overall criterion when changing glazing areas is that for buildings with specific workstations such as offices, every workstation should have a distant outdoor view, and a daylight factor of at least 1.5 per cent.

Shading

Shading is an integral part of good daylighting design, particularly on facades that are insolated at some time of the year. This is largely because direct sunlight is between five and ten times the brightness of the diffuse sky, but due to weather, it is not predictable.

Fixed shading

Shading may be fixed, relying on its geometry to selectively obscure parts of the sky through which the sun passes. These devices could be in the form of fixed louvres, overhangs and/or deep reveals.

One type of fixed shading that should be avoided is fixed grids or screens. These are not geometrically selective, do not improve the thermal performance of the envelope (unlike reducing glazing area) and seriously disrupt the view.

Adjustable shading

Shading can be adjustable in three ways:

1. variable geometry such as in louvres or fins;
2. variable transmission – also achieved by closable louvres or fins;
3. deployable – i.e. can be deployed in or removed completely from the aperture.

Shading devices may be located inside, outside or mid-pane.

Well-designed shading has a positive effect on comfort, reducing room overheating, local overheating from radiation, and glare. If it is adjustable, it allows the occupant to make compromises between view and shading if necessary, and provides one of the more significant adaptive opportunities that promotes comfort satisfaction.

In choosing a type of shading for retrofit, its impact on natural ventilation must be considered. For instance, a translucent roller blind will completely obstruct airflow, whereas louvres will allow it to a greater or lesser extent.

The properties of shading devices and their suitability are summarised in Table 7.1. An overall criterion is that for buildings with specific workstations such as offices, every workstation should have a distant view, and a daylight factor of at least 1.5 per cent.

Table 7.1 Properties of shading types and their suitability

	Shading type	Orientation	View	Nat vent (in limiting conditions)	Daylight (in limiting conditions)	Seasonal response	Modulation	Notes
	Overhangs Fixed Retract	 180 +/– 30 180 +/– 30	 Good Good	 Good Good	 Medium Good	 Medium Good	 None Good	 e.g. Canvas awnings + adjustable geometry
	Louvres Fixed Adjust Retract. Retract.+ adjust	 180 +/– 30 All 180 +/– 30 All	 Med – poor Med – poor Med/good Med/good	 Good Good Good Good	 Medium Good Good Good	 Medium Good Good Good	 None Good Medium Good	 View influenced by blade module size and geom. 'Good' applies to when retracted
	Fins (vertical) Fixed Adjust	 90, 270 +/– 20 90, 270 +/– 45	 Med – poor Med	 Good Good	 Medium Good	 Medium Good	 None Good	 View influenced by blade module size and geom.
	**Blinds** Retract	 All	 Poor/good	 Poor	 Good	 Good	 Medium	 'Good' applies to when retracted
	**Perforated screens** Fixed	All	Poor	Med – poor	Poor	Poor	None	Not recommended

Source: N. Baker

Notes to accompany Table 7.1:

i Orientation all implies that performance is not orientation-sensitive, although in general, there would be no demand for shading on facades orientated towards the poles (N or S) +/—45°.

ii Adjustable louvres and fins will have poor view performance and poor natural ventilation performance, when completely closed.

iii Natural ventilation limiting conditions refers to situations requiring the shading to be deployed, that is when there is an overheating risk. Good implies that natural ventilation is not impeded.

iv Daylight limiting conditions refers to minimal daylight availability when there would be no requirement for shading. Good implies that the shading device causes no reduction in daylight transmission in these conditions.

v Distribution refers to the ability of the shading device to improve daylight distribution, thereby lowering the total daylight energy (solar radiation) required.

vi Seasonal response refers to the ability of the shading device to respond to different sun angles at different seasons.

NATURAL VENTILATION

The existing building will already rely on either natural ventilation (apart from toilets, kitchens, etc.), mechanical ventilation or combined ventilation, heating and cooling (air conditioning). Some older buildings will have had various levels of air conditioning installed during the building's lifetime, often in response to poor environmental standards due to inherent design deficiencies. These deficiencies typically include excessive solar gain and heat loss through over-glazed leaky facades, poor indoor air distribution and poor control of high pollution areas. If these deficiencies can be removed or mitigated, it should be an objective of the retrofit to return the building to natural ventilation.

In older buildings, infiltration (uncontrolled ventilation due to a leaky envelope) may be making a significant contribution to air quality, and this could be compromised if the upgrade to the fabric includes the reduction of infiltration. This must be compensated for by providing purpose-made controllable fresh air sources, either driven by natural or mechanical means. A guiding principle is 'build tight – ventilate right', meaning that ventilation should be demand led, and if naturally driven, the wide variation in the driving forces of wind and stack effect compensated for by controls.

The three functions of ventilation

It is important to separate out the functions of natural ventilation. These are:

1. provision of a minimum air quality (dilution and removal of pollutants);
2. the removal of unwanted heat gains (to avoid overheating);
3. to provide air movement for direct physiological cooling.

When ambient temperatures are low, only the first function is required, and the relatively low rates can easily be provided by wind or stack effect. At medium ambient temperatures, in the absence of wind, in densely occupied areas, natural ventilation may be unable to provide sufficient fresh air, and mechanical back-up should be considered. This can be a very satisfactory solution in a well-controlled predominantly naturally ventilated building, where the mechanical back-up is controlled by detecting CO_2 levels, a good indicator of indoor air quality. The mechanical equipment can be located in elements that are part of the passive system, such as stacks or roof ventilators.

For the second and third functions, high air change rates are required, necessitating large openable areas. These are normally provided by windows, thus combining the three functions of daylight, view and fresh air into one element, reinforcing intuitive control by the occupant.

However, there may be some circumstances where due to ambient noise or pollution, opaque ventilation components (flaps, dampers, etc.)

incorporating sound attenuation and or filtration are required. In terms of ambient noise control, the design of the window can have considerable influence as illustrated in Figure 7.7, and this should be considered when specifying retrofit windows.

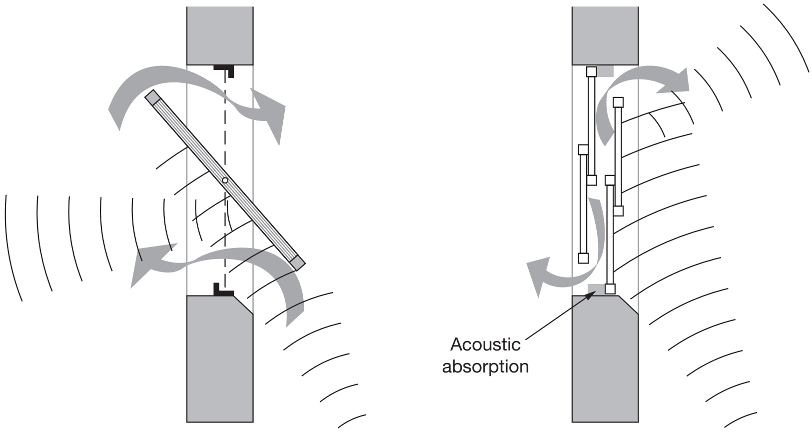


Figure 7.7 Window design for enhanced noise reduction for natural ventilation in noisy locations

Source: N. Baker

Indoor air quality

The provision of minimum air quality, as defined above, is normally concerned with removal and dilution of CO_2, water vapour and bio-odours. Bio-odours – produced by the occupants – are in themselves harmless, but act as a warning that air quality due to occupation may be insufficient. There may also be other pollutants produced by activities associated with occupation, particularly in manufacturing processes, cooking and even some office equipment (e.g. ozone produced by photocopiers). These pollutants may or may not produce odours detectable by the occupant. Toxic pollutants with no odour are the most dangerous (e.g. carbon monoxide), and where there is risk of these, special detectors must be installed. Some will be dealt with by specialist local extract ventilation.

Of particular relevance to a newly occupied building after retrofit, is the outgassing of new materials. This is mainly due to volatile organic compounds (VOXs) present in adhesives, paints and some recently manufactured materials such as laminates and textiles. Again, these may or may not produce odour, and generally will not be highly toxic since this will be covered by regulation. But they may cause discomfort to occupants, and possible more serious and unpredictable symptoms in certain individuals due to allergic reaction.

Outgassing usually takes place over a short period relative to the life of the building, and may have progressed sufficiently before full occupation. There is some evidence that the process takes place quicker at higher temperatures, and this could be arranged in the pre-occupied period. Once the building is occupied, the effects of residual outgassing can be mitigated by a higher than normal ventilation rate, for the first few weeks. The building could also be heated during the unoccupied period.

NOISE AND ROOM ACOUSTICS

The comfort and well-being of occupants can be affected by the acoustic properties of a building in four ways:

1. The ingress of noise from outside through natural ventilation.
2. The noise level inside the building due to sounds generated within the building. This may be due to the transmission of noise from another part of the building (including structure-borne sound) or the reverberation of noise generated within the space.
3. Poor speech intelligibility due to long reverberation time.
4. Loss of privacy due to the transmission of sound in the building.

All of these may be influenced by the specification of the retrofit.

The control of external noise can be achieved by window design. It can also be controlled by external treatments to the site landscape. This can include the provision of barriers or in some cases the removal of reflecting surfaces. It is quite conceivable that noise control measures carried out as part of site landscaping could enable natural ventilation to be viable, where otherwise a sealed air-conditioned building would be the only solution.

Conflicts with natural ventilation

Unfortunately, the provision of flow paths for natural ventilation within the building often link rooms and permit sound to travel throughout the building. Where this is achieved through casual openings (doors, internal windows, etc.) it is difficult to control and may have to necessitate a compromise by the occupants between thermal and acoustic comfort. In some cases circulation spaces could be used or, in more engineered solutions, bypass ducts can be included to achieve cross-ventilation in double-banked rooms.

Loss of privacy is closely related to noise transmission. The main difference is that intelligible speech needs to contain high frequencies, which means that reverberant sound (see below) is less likely to cause a problem. Privacy problems are commonly caused by flanking transmission or by first reflections from ceilings. Curved reflective surfaces may cause some focusing effects and amplify reflected sound with unexpected results.

Reverberation and exposure of thermal mass

Due to the ear's wide-ranging sensitivity to sound energy (a range of 10^{12}), audible sound will persist in a room until the energy is absorbed at the room surfaces to a very low level. This time, the reverberation time (RT) is typically in the order of one or two seconds for an acoustically 'live' room, or as short as 1/10 second for an absorbent room.[2]

Reverberation has two main effects on the room acoustic. First, long RTs cause a build-up of reverberant sound that includes unwanted noise – either generated within the space, or outside – and reduces speech intelligibility by overlapping the high frequency syllable sounds due to multiple reflections remaining audible.

The absorption being referred to here generally takes place when the sound is reflected off the walls, floor and ceiling of the room; highly absorptive finishes involve fibrous and porous layers and/or flexible panels. Unfortunately these finishes also thermally isolate the room from any massive structural materials, and thus good acoustic performance is in direct conflict with the provision of thermal mass for temperature control.

There are measures that can be taken to affect a compromise. Exposed floor slab soffits, particularly effective for thermal transfer, can be provided with hanging acoustic absorbers which still allow convective and some radiative transfer of heat, as shown in Figure 7.8. Soft furnishing and partitioning systems can also provide acoustic absorption.

Design solutions should seek to balance exposure of thermal mass with acceptable acoustics rather than allowing one consideration to dominate. A good compromise will take account of the likelihood of overheating, and a minimum acceptable acoustic standard, and will probably require some calculation and analysis.

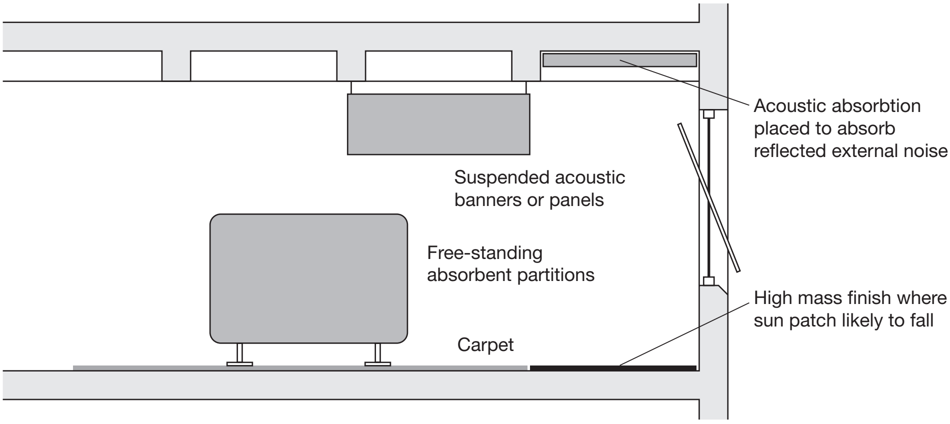


Figure 7.8 Acoustic absorbing banners and partitions providing absorption whilst leaving thermal mass in floor/ceiling slab exposed

Source: N. Baker

SERVICES AND CONTROLS – AIR CONDITIONING: AVOIDANCE OR REDUCTION

It is now well known that as a population, air-conditioned buildings use significantly more energy than naturally ventilated buildings. There is thus a large incentive to adopt as a strategy the avoidance of air conditioning. This will be facilitated by reducing gains as much as possible, and using the building to mitigate the effects by means of thermal mass and ventilation.

However, there may be some circumstances where air conditioning may be unavoidable. This demands two considerations – first, to minimise the air-conditioning load by passive means and, second, to provide the cooling and air handling by the most efficient plant available.

A third consideration is that air conditioning may only be needed in certain parts of the building and at certain times of the year. The way in which the transition is made is important – for example for a space for which natural ventilation is adequate for all but extreme hot weather – it is very important that the natural ventilation is discontinued when mechanical cooling is present. The strategy of partial air conditioning is often referred to as 'hybrid' or 'mixed mode'.

The design and specification of the services during retrofit will have great influence on the success of the building both for its energy performance and the provision of comfort. Here we concentrate on a few key design parameters that are likely to affect the comfort and well-being of the occupants. These mainly involve the interfaces between the occupant and the services, i.e. the heat (and 'coolth') emitters and the controls.

Sick Building Syndrome

Sick Building Syndrome (SBS) refers to the observation that in certain buildings, complaints from occupants of a particular set of symptoms are more common than usual. Typically these symptoms include headaches, irritation of the nose and throat, sore eyes and occasionally skin irritation. The type of building in which SBS is most commonly present is the deep, open-plan sealed building, relying heavily on mechanical ventilation (or full air conditioning), artificial lighting and with little or no personal environmental control.

It is also common in older buildings of this type which may indicate that it is due to a degradation of the mechanical services. In particular, air quality can be seriously compromised by poor maintenance of filters and poor cleanliness of ducts and grills. The use of recirculation can result in the distribution of bacterial and fungal pathogens, especially if clogged filters are automatically bypassed.

SBS is far less prevalent in shallow-plan naturally ventilated and daylit buildings. If the building to be retrofitted allows these passive features to be restored, it would be the best strategy. If the building to be retrofit is a deep-plan highly serviced building with a history of SBS, this presents a bigger challenge, and it would seriously suggest that at least the mechanical services need major maintenance or replacement and upgrading. The provision of user controls (discussed below) would also be essential.

Heat emitters

It has already been mentioned that improvements to the envelope insulation and ventilation control will not only lower the overall heat demand, but will also reduce the temperature differences within the external envelope. The absence of areas of high heat loss, and the lower demand overall, means that heat emitters such as low-temperature underfloor or radiant ceilings are viable. These have a high level of occupant satisfaction reported when used at low outputs. Both systems are also suitable for cooling, if it is considered that acceptable summer conditions cannot always be met by passive means.

The building may already have a perimeter fan-convector system that was designed to offset the originally high perimeter losses. If these losses have been reduced significantly due to fabric and glazing upgrades, their output can be reduced simply by reducing water temperature difference (ΔT). This improves boiler efficiency and is compatible with low-energy systems such as heat pumps and solar thermal.

Again due to the reduced perimeter losses, it may be better to remove the fan convectors and replace with simple panel radiators of lower output. These carry the significant comfort advantage that they are silent and do not contribute to dust distribution, and the operational advantage of low cost and low maintenance.

However, if fresh air is introduced by passive vents associated with the windows, these will remain a point of concentrated heat load, which now becomes a larger proportion of the total load. This must be dealt with in order to prevent local comfort problems, either by combining a controlled fresh air intake with the perimeter convectors or panel radiators, or by a stand-alone mechanical fresh air supply for use during low ambient temperatures. This can be demand controlled (by CO_2 concentration control point), and pre-heated, possibly with heat recovery from extracts in central zones. Heat recovery from exhausted ventilation air, together with very high levels of insulation, is an essential part of the Passive House approach for new buildings. This leads to very low auxiliary heating demand. A less extreme specification has been developed for retrofit called EnerFit.

Whilst cool floors are a viable option for small cooling loads where there are no carpets, they may present condensation risk if carpets are present, due to the temperature drop over the thickness of the carpet. Chilled beams and ceiling panels are a more familiar coolth emitters, but mechanical cooling should only be resorted to when passive means cannot achieve the minimum standards, and then only in 'hybrid' mode where mechanical cooling is applied intermittently and locally in response to peak conditions.

The comfort band can be significantly extended by the use of room fans to create air movement; typically a reduction of effective temperature of around 3°K can be achieved at practical air velocities. These can be ceiling mounted or located at desk level, the latter being preferable in that, like task lighting, they offer more personal control and thus another important adaptive opportunity. With ceiling fans used for cooling, there is also the danger that they will direct warmer stratified (and possibly more polluted) air down onto the occupant.

Artificial lighting (and integration with daylight)

Great progress has been made in luminous efficacy fluorescent light sources and, together with improved luminaire design, has led to a steady lowering of the installed power (W/m^2). The use of high frequency control gear has eliminated flicker and improvements in colour rendering have both contributed to improvement in visual comfort. This means that unless the building has received a recent lighting upgrade, the artificial lighting will be a prime candidate for the retrofit.

Task lighting

There is now widespread agreement that task lighting is potentially beneficial both for energy efficiency and visual comfort, but many lighting schemes fail to reach their full potential. This is because task lighting is often installed that provides local *lighting in addition* to high levels of general lighting. From an energy perspective, the purpose of task lighting is to allow a lowering of the ambient room illuminance (from say 300 lux to 150 lux), by providing higher illuminances at the workstation. Task lighting will also allow much greater use of daylight, since it will extend the time (and area of the floor) for which daylight provides sufficient light for circulation and non-demanding visual tasks.

If the task lighting is too powerful, and has no means of dimming control, this principle will be undermined, since high levels of workstation illuminance (say 750–1,000 lux, quite easily achievable with task lighting), due to adaption of the eye, may cause a background illuminance of 150 lux to appear inadequate. It goes without saying that the task light sources should be high efficacy fluorescent or LED; if incandescent sources such as tungsten halogen (still popular in domestic equipment) are used much of the energy saving will be lost.

Task lighting is also beneficial for visual comfort as, due to its controllability, it complies well with the principle of adaptive opportunity. It is particularly appropriate in workplaces where much of the information is communicated by luminous screens, where high levels of task illuminance are not needed or even undesirable.

Spatial design of lighting

Less progress has been made in the spatial design of lighting. Luminaire designers have concentrated on low-brightness sources,[3] often set in a suspended ceiling in a downlighter configuration. This results in a low-luminance ceiling and the perception of a hidden light source, with a rather nocturnal quality. Whilst this may be suitable for retail display, or a hotel foyer, it is not a good daytime working environment. This is because it does not emulate the luminance distribution of the natural sky condition and it is difficult to integrate with daylight.

There is now serious consideration being given to how visual cues, such as lighting colour and configuration, may be effective in influencing our natural circadian rhythms and hence health and well-being. Whilst this is a relatively new area, it seems likely that lighting schemes with high ceiling luminance are better for daytime occupants. This allows far easier integration with daylight, since diffuse sources with both upward and downward light output can supplement daylight. It is also compatible with occupant-controllable task lighting.

Controls

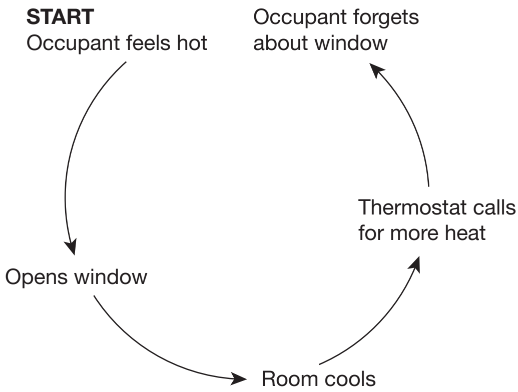
One of the principles of adaptive comfort is that people are more satisfied with their environment if they feel they have some measure of control over it. Efforts to engineer the perfect neutral environment have always failed to eliminate a residual level of dissatisfaction. There is a view (Baker and Standeven, 1997) that we have an innate desire to respond to our environment – the more neutral it becomes, the more sensitised we become to a particular parameter. The adaptive comfort principle, on the other hand, is to provide a 'good enough' environment, and provide the means by which the occupant can respond.

However, the principle of personal control over the environment has to be set against two constraints. First, in many situations occupants share the space with others, sometimes, in the case of open-plan offices, too many people for a consensus view to be found. In the case of cellular offices, occupied by two to four people, consensus is easier and personal control is more successful. This suggests that the open-plan solution is not ideal for the compromise between energy efficiency and health and well-being. However, the problem can be mitigated by providing some personal control – such as task lighting and desk fans, and permitting and even encouraging a more mobile working pattern, where occupants may use temporary locations away from their home station. This may involve shared facilities (warm-desking) and need not necessarily lead to a high space provision per occupant.

Second, personal control should not be allowed to seriously compromise energy efficiency. For example, opening a window because a heated room is too hot may achieve comfort, but will result in a waste of energy. Ironically, the invention of the thermostat has created this problem, as illustrated in Figure 7.9. Here, control technology can provide an answer; it is not difficult to integrate a window sensor with the local heating and ensure that the heating is discontinued, or at least set at a low level, as soon as the window is opened. This must not be seen as a 'punishment'; it is simply achieving the wishes of the occupant in a more energy-efficient way.

Figure 7.9 The impact of the thermostatic control to break the natural feedback loop in occupant control

Source: N. Baker



Another area of 'innocent' misuse is in lighting control. Whilst we are aware of too little illumination, we are much less aware of over-illumination – at least at levels found in buildings. Thus, it is not uncommon to find lights still switched on in a room when daylight has become completely adequate. The simple answer is a photo-sensitive control which fades the lighting gradually, but allows it to be overridden if for any reason an occupant feels the need for extra light. After some time delay, or coinciding with a particular disruption to the daily pattern such as lunch break, the lights will again be returned to off.

Caretaker controls

We have called this the 'polite caretaker' function. The control system anticipates human interaction, tolerates a small measure of 'illogical' behaviour, but gently returns the building to a base level environmental status. Fortunately, modern technology, including IT and wireless control communication, has made sophisticated control of buildings possible and affordable. The development of digital control now means that individual actuators can be addressed with the minimum of infrastructure.

However, in the past, this has been used as an excuse to have a high level of central control and automation – the so-called 'smart' building. We see it rather differently. This wonderful facility should be used to welcome the adaptive behaviour of the occupant, but to ensure that it neither conflicts unreasonably with other occupants, nor the energy-efficient operation of the building. Perhaps we should be moving towards the 'polite' building: polite to the occupant and polite to the environment.

THE INTEGRATED APPROACH

An underlying theme in this chapter has been that measures to improve energy efficiency can also improve comfort and well-being. Looked at another way, it follows that for a given level of comfort and satisfaction, certain retrofit specifications can lead to greater energy savings than others. The avoidance of air conditioning is a good example.

Another theme has been the provision of adaptive opportunity. Less energy will be used by providing a 'good enough' environment where a modest level of behavioural response is possible than attempting to provide a closely controlled 'ideal' environment.

Finally, it is clear that many measures have a mutually supportive effect – thus reconfiguring windows may improve daylighting, improve view, reduce glare and overheating, and open up possibilities for natural ventilation with intuitive occupant control. These multiple benefits may be more than just technically supporting, but also psychologically, i.e. the whole is greater than the sum of the parts. This is borne out by the findings of the 'forgiveness factor' by Building Use Studies (Leaman and Bordass, 2007). On the other hand, some actions may have undesirable effects on other environmental parameters – for example, exposing thermal mass can have adverse acoustic effects.

A further psychological factor is the perception of 'natural causes', which helps the occupant to understand the non-neutral environment and, we find, become more tolerant of it. Closely related to this is the degree to which the building allows contact with nature.

This suggests that the designer must not become too focused on any one environmental issue, but be aware of their interactions, and both the positive and negative consequences on the indoor environment as a whole.

NOTES

1 Defined as the ratio of the overall satisfaction score to the average score of individual environmental performance indicators.
2 It is predictable, using Sabine's formula: $T = 0.016\ V/\Sigma\alpha A$ where V is the volume of the room, α is the absorption coefficient of the room surface element and A is the area.
3 This refers to the apparent brightness of the luminaire when viewed at an oblique angle from a normal sitting position.

REFERENCES

Baker, N. and Standeven, M. (1997) 'A behavioral approach to thermal comfort assessment', *International Journal of Solar Energy*, 19: 21–35.
Fanger, P. O. (1970) *Thermal Comfort Analysis and Application in Environmental Engineering*, Vanloese: Danish Technical Press.
Guedes, M. C. and Matias, L. (2009) 'The use of adaptive thermal comfort criteria in office buildings: A study in Lisbon', *Renewable Energy*, 9(9): 2357–61.
Humphreys, M. (1978) 'Outdoor temperatures and comfort indoors', *Building Research Practice*, 6(2): 92.

Leaman, A. and Bordass, B. (2007) 'Are users more tolerant of "green" buildings?', *Building Research and Information*, 35(6): 662–73.
Papairi, K. (2004) 'Daylight perception', in K. Steemers and M. A. Steane (eds) *Environmental Diversity in Architecture*, London: Spon Press.
Rassia, S. Th., Alexiou, A. and Baker, N. V. (2010) 'Impacts of office design characteristics on human energy expenditure: developing a "KINESIS" model', *Energy Systems*, 2(1): 33–44.