WHAT COLOUR is YOUR BUILDING?

Measuring and reducing the energy and carbon footprint of buildings

David H. Clark

Appendix H

Reducing operating carbon

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Appendix H: Reducing operating carbon

Every new building we build and every building we renovate have the promise to make or break a low carbon footprint for decades to come - this is an opportunity we simply cannot afford to lose.

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Contents

This appendix provides calculations, further information and guidance to support Chapter 6 (Ten steps to low carbon).

Published by RIBA Publishing, 15 Bonhill Street, London EC2P 2EA
www.ribaenterprises.com

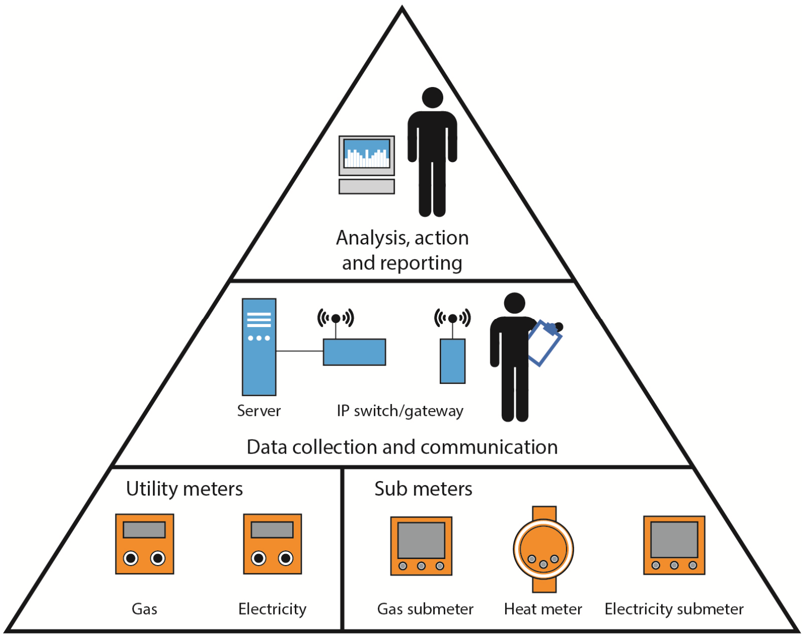
Issue 1.1: 14 July 2013

H1. UNDERSTANDING HOW ENERGY IS USED

H1.1 Metering

Having a clear energy metering and monitoring strategy is an essential step for reducing energy consumption in buildings. Without this, you're 'flying blind'. The key components are:

- Half hourly utility meters on electricity, gas and water supplies to the building.
- Half hourly sub meters on all energy systems (electricity, gas and heat) so that 90% of the energy consumption can be monitored by end use.
- A data collection system on a computer or remote server which collects data from the meters via a communication link (e.g. hard wire, radio, ethernet or mobile phone network) and stores it in a database.
- Energy reporting software to process and analyse energy data, either on-site or on a web server. This could automatically report exceptional use and also compare performance across a portfolio of buildings.
- Someone to review the data and take action. This is the most important part. Meters need to be read and their data collected, analysed and used. Sharing this data with design teams and others (e.g. via the CarbonBuzz website) provides a useful feedback loop to avoid overdesigning plant and improving control strategies on future projects.



* A heat meter is a device which measures water flow and temperatures to calculate the heat or cooling energy used.

Fig H.1: Components of a metering strategy

FURTHER GUIDANCE
• *Building energy metering*, CIBSE TM39.   • *Green gauges: Lessons learnt from installing and using metering and monitoring systems in low carbon buildings*, Carbon Trust CTG037.

H1.2 Energy management

Successful energy and environmental management is a continuous process. An energy management system or plan should include the components shown in Table H.1.

Action	Comment
Establish an energy or carbon policy	Set out a commitment at board level to reduce the operational carbon footprint.
Identify the energy impacts	Establish both the direct impacts and indirect impacts that the user controls or influences (e.g. landlord and tenant energy use).
Identify applicable legal requirements	These can include energy ratings on sale or lease, carbon reporting, carbon taxes, mandatory air conditioning inspections, and so on.
Establish measurable objectives and targets	Use energy rating tools and/or relevant industry benchmarks – refer to Chapter 2 and Appendix C.
Establish, implement and maintain a programme of actions	Make a plan to achieve the objectives and targets. This should be aligned with relevant asset management plans and maintenance schedules.
Define roles and responsibilities	Clearly assign responsibilities and reporting structure back to board level to deliver the plan.
Provide appropriate training	Training should be relevant to the different roles – energy manager, facility manager and occupants.
Communicate the plan to building occupants	Getting 'buy-in' is essential – refer to Section 6.10 in Chapter 6.
Monitor and report performance and compliance	Make progress in reducing energy visible. Develop a reporting mechanism and update the plan based on continuous feedback.

Table H.1 Typical components of an energy management plan

The energy management plan should also seek to realise any opportunity to 'build in' energy and resource efficiency at times of change such as fit-out, modification and equipment purchase or leasing.

FURTHER GUIDANCE

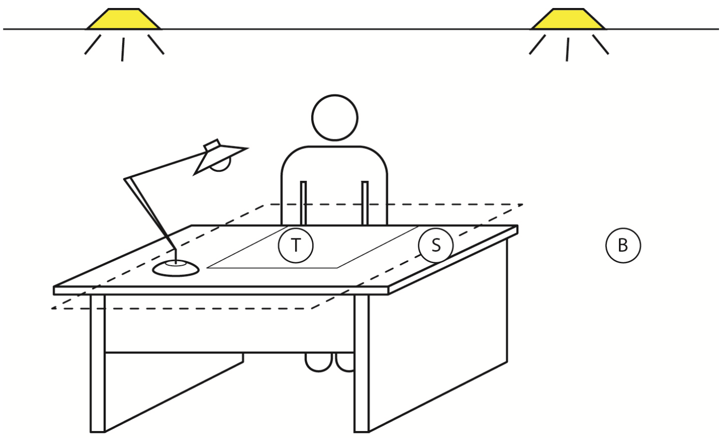
- *Energy management: a comprehensive guide to controlling energy use*, CTG 054, Carbon Trust
- *ESD operations guide for owners, managers and tenants*, Australian Government, 2009
- ISO 14000 – international series of standards for Environmental Management Systems
- ISO 50001 – Energy management systems: Requirements with guidance for use
- www.climatechange.gov.au/government/initiatives/green-lease-schedule/energy-management-plan.aspx

H2. DESIGN ASSUMPTIONS – LIGHTING AND COMFORT

H2.1 Lighting

The area of task to be lit is defined in BS12464:1 (2011) as an area of 0.5m x 0.5m on the working plane. If light was provided only in this location, with no lighting elsewhere, then this would cause eye strain between the lit area and the darker background. While our eyes can cope with very large ranges in ambient light levels, from 100,000 lux (bright sunlight) to 0.001 lux (moonless clear sky), they cannot register information across this range at the same time.[1] It takes time to adapt from a bright space to a dark space, and consequently wide ranges of brightness within the field of view are uncomfortable.

To avoid sudden changes in lighting levels, uniformity ratios are used. The uniformity ratio is the minimum lux level divided by the average lux level in the lighting zone. BS12464:1 (2011) defines three zones: task, immediate surround and background and the minimum uniformity between these. Figure H.2 shows the minimum lux levels for screen- and reading-based tasks and in the adjoining zones.



ZONE	AREA	UNIFORMITY	MIN LUX LEVELS	
			SCREEN	READING
Task (T)	0.5m x 0.5m		300	500
Surround (S)	1.5m x 1.5m	0.4	120	200
Background (B)		0.1	30	50

Fig H.2 Design lighting levels for office based tasks (from BS 12464:1 – 2011)

H2.2 Thermal comfort standards and factors

The two most recognised thermal comfort standards for offices are ISO 7730 and ASHRAE Standard 55.[2] They take slightly different approaches but both are based on predicting the percentage of dissatisfied occupants. The standards are referenced by the major rating tool systems in order to award thermal comfort credits based on building simulation of the design:

- BREEAM – a maximum of 5% dissatisfied using ISO 7730 (which equates to a peak operative temperature of 24°C in summer according to CIBSE Guide A).
- LEED – a maximum of 20% dissatisfied using ASHRAE Standard 55.
- Green Star – 1 point for <28% and 2 points for <10% dissatisfied using ISO7730.

The UK Health and Safety Executive refers to a minimum 80% of satisfied occupants.[3] ISO 7730 and ASHRAE Standard 55 predict thermal comfort using six physical factors. Table H.2 summarises how these factors might typically affect a person in summer and winter.

	Summer	Winter
Air temperature	Temperatures above 28°C are usually considered uncomfortable in offices.[4]	Temperatures below 20°C are usually considered uncomfortable in offices.[5]
Radiant temperature	Sitting in direct sun next to a window can be uncomfortable. Cool surfaces will absorb heat radiated from the body improving comfort.	Warm surfaces radiate heat to the body increasing comfort (the principle of radiative heating). The body radiates heat to colder surfaces, such as a cold window, causing discomfort.
Humidity	High humidity environments (>70% relative humidity) have a lot of water vapour in the air, which reduces the ability of the skin to sweat. Typically humidity ranges between 30% to 60% RH are desirable. Over cooling by air conditioning (<30% RH) can dry the air too much causing discomfort (dry skin or dry eyes) and creating issues with static electricity.	Dry air (less than 30% RH) produced by high temperature heating sources can be uncomfortable.
Air movement	Breezes, due to natural ventilation or fans, increase evaporation of sweat from the skin, increasing comfort. This is why ceiling fans are common in hot, humid environments.	Draughts create discomfort. This can also bring in cold air, lowering the air temperature.
Clothing	Wearing light clothing on hot days improves comfort. Wearing a suit all year round requires more cooling to maintain comfort.	Wearing warm clothing on cold days improves comfort.
Activity (metabolic rate)	Sedentary activity (e.g. sitting at a desk) is more comfortable than, say, jogging in the office. Metabolism varies by individual (size, weight, age, fitness level and gender) and can affect whether someone feels hot or cold.	Jumping up and down to keep warm suggests the office is too cold.

Table H.2 Thermal comfort factors

H2.3 Thermal comfort – implementing a set point strategy

If the seasonal set point strategy outlined in Table 6.5 in Chapter 6 is adopted there are issues that need to be addressed to reduce the potential for complaints when the temperature band is widened. These include:

- Communicating intentions before implementing and seeking 'buy-in' from occupants.
- Adjusting the set points gradually over a few weeks – don't just go from 23°C to 26°C overnight.
- Relaxing the formal dress code to allow adaptation to conditions (refer to section H2.4).
- Fixing leaky facades to reduce draughts in winter (refer to section H3.5).
- Install measures to reduce solar gain (better blinds or glazing film) to reduce radiant temperatures in summer for occupants near windows (refer to section H3.7).
- Checking that zoning of heating and cooling systems reflects the different heat gains and losses on the floor plate – in particular perimeter zones on each face, internal zones and cellular accommodation are all controlled separately (refer to section H5.8).
- Checking that air flows, controls and diffusers in mechanically ventilated spaces are correctly set up so that air is reaching the right spaces and is mixed properly, and not causing draughts or stagnant areas (refer to section H4.13). Internal partitions can often disrupt the intended air flows.

The benefits of a good engagement process are illustrated by the following example from Australia:[6]

'An organisation wanted to trial increasing the temperature set point of their air-conditioning to reduce energy use. Staff were engaged from the outset with regular communiqués and updates. Not only did energy consumption reduce significantly but the number of complaints about comfort actually decreased. One senior manager stated emphatically at the beginning of the process that 'I don't do layers and I only wear stilettos!' Three weeks later she proudly sported a new look involving a sweater and sensible shoes.'

Another example from Australia further supports the view that thermal comfort is often all in the mind. At a seminar in 2012, a government organisation discussed how they had decided to use a floating set point (which adjusts to reflect changes in external temperatures) with an increased internal temperature during the summer. Complaints immediately started about it being too hot due to the changes. After 3 weeks, the organisation pointed out to staff that the changes hadn't been made yet. They subsequently introduced the set point changes and thermal comfort complaints stayed at background levels (i.e. no increase compared to normal).[7]

H2.4 Super Cool Biz – changing clothing and attitudes in Japan

In 2005 the Japanese Ministry of the Environment (MOE) began advocating the Cool Biz campaign as a means of reducing electricity consumption by limiting the use of air conditioning.[8] The idea was for office workers to shed their suits and turn the air conditioning set point up to

28°C. The campaign gathered momentum with 57% of surveyed respondents saying that Cool Biz had been implemented in their workplace in 2009.

Following the earthquake and tsunami in March 2011, and the damage to the Fukushima nuclear power plant leading to energy supply issues, a new Super Cool Biz campaign was launched – refer to Figure H.3. Going beyond simply removing the suit jacket and tie, the Government encouraged workers to wear outfits appropriate for the office yet cool enough to endure the summer heat.

Fig H.3 Example Super Cool Biz business clothing range in Japan (source: Uniqlo)

H2.5 Cool Biz in Oz

In 2006 the author undertook a set point study for a state government department in Australia that was interested in adopting the Cool Biz initiative. The proposed widening of the internal temperature bands to 20–26°C was estimated to deliver energy and greenhouse savings of approximately 4% per annum. For the department portfolio of 93,000 m^2, this represented an annual cost saving of approximately A$100,000 and greenhouse gas savings of 1,375 tCO_2. The cost to update the Building Management System (BMS) software in the portfolio buildings to enable the wider temperature bands to be delivered (by adjusting the set point of the heating / cooling systems) was estimated to be A$119,000, giving payback of just over one year.

As part of the study, an analysis of thermal comfort complaints (too hot or too cold) in all the portfolio buildings was undertaken. Some buildings were too cold in the summer while some were too hot, and some respondents experienced both conditions during a season. Figure H.4 summarises the complaints by season for the portfolio for the 12 months prior to the study.

Further analysis of comfort issues in each building was recommended to identify how some of the existing problems could be addressed, and how changing the set point might increase the number of complaints to the facility managers.

The development of a staff engagement plan was also recommended so that staff would understand which changes were being proposed and why. A change in culture would be needed to make it work, particularly related to dress codes. This would require a consultative process, with feedback from staff before, during and after the proposed changes. Dialogue with relevant OH&S committees and unions during this process was recommended.

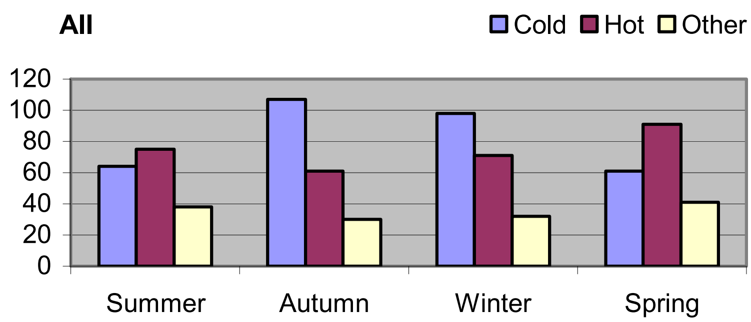


Fig H.4 **Thermal comfort-related complaints by season in a government office portfolio in Australia**

Primarily because the initiative required cultural change and consultation, and not just a tweak to the building control systems, it was never implemented. If the strategy had been rolled out across all office buildings (government and commercial) in the city (an assumed net lettable area of 7,000,000 m^2) then this had the potential to save 107,000 tCO_2 and A$7.5 million in energy costs (based on 2006 prices).

H3. BUILDING FABRIC

H3.1 The influence of climate

The facade is the thin layer between the outside and internal environment. Before the invention of air conditioning, buildings were designed to respond to the climate using locally available materials, as in traditional architecture and indigenous housing. Now most commercial buildings look the same the world over – refer to Figure H.5.

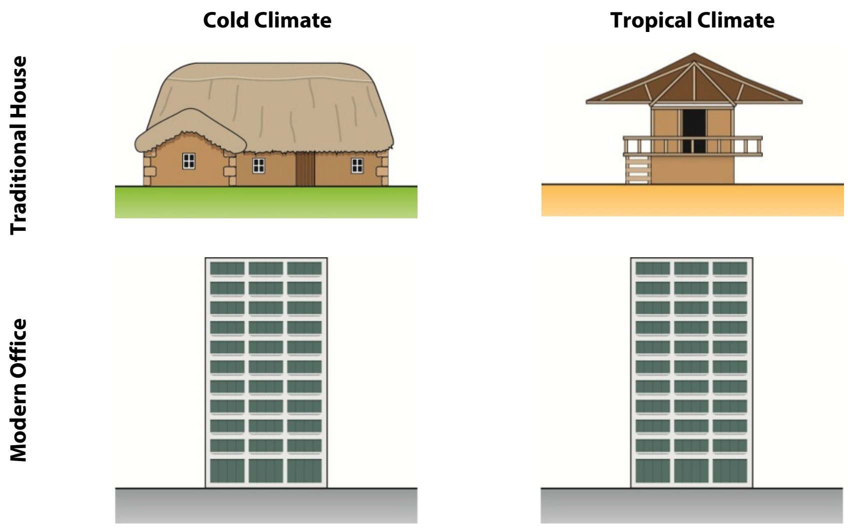


Fig H.5 **Vernacular architecture before and after air conditioning was invented**

Figure H.6 shows the heating and cooling degree days for different cities around the world, together with the typical average maximum and minimum temperatures during the hottest and coldest months respectively. The heating degree days use a base temperature of 15.5°C, indicative of the external temperature below which heating is typically required in offices. The cooling degree days are for a base temperature of 20°C, indicative of the external temperature above which cooling might be required in offices.

As the heating degree days increase, both the U-value and air tightness are important in reducing heat losses through the façade (as is using heat recovery to reduce the energy to heat the fresh air supply). In warmer climates, keeping heat out takes precedence and so the focus shifts to reducing solar heat gain through the use of shading systems and/or glazing performance. In commercial buildings it is not quite as simple as this, due to the high internal heat loads from computers, servers and people. A highly performing façade on an air conditioned building may, in certain circumstances, actually increase the cooling load and therefore the building's energy consumption. This is why façade design usually requires detailed analysis to optimise performance and life cycle cost.

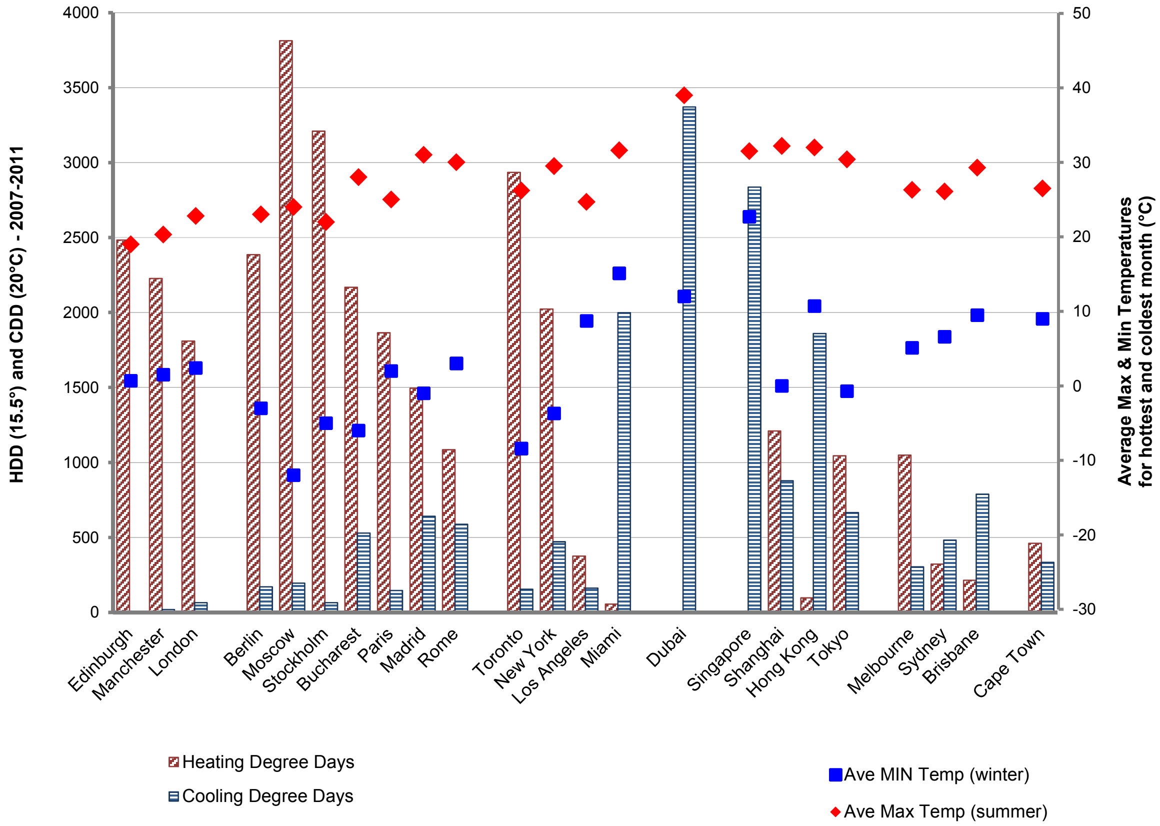


Fig H.6 **Heating and cooling degree days and average max/min temperatures (source: chart prepared using data from www.degreedays.net, www.metoffice.gov.uk, www.wordtravels.com and www.worldclimate.com)**

H3.2 Façade design components

Table H.3 summarises some of the key energy and environmental factors which affect the design of facades and provides some potential low energy responses.

	Issues	Potential low energy response
Daylight and views	Full height glazed walls appear to provide better daylight and views than discrete windows. However, glazing below desk height does not contribute much useful light, and views out are often blocked by the desks and boxes of stuff people often push up against them (refer to Figure H.7). Is having a view out while plugging in your phone charger under the desk really important? Vertical spacing between windows needs to take account of uniformity of daylighting in a room.	A glazed area of 40% of the façade area (above the working plane of 700 mm) typically provides reasonable daylighting. High level glazing allows daylight to penetrate deeper into a space. Glazing with a Visible Light Transmission (VLT) of at least 60% is usually desirable. Refer to section H3.10 for daylight modelling results for different façade options and details of the Useful Daylight Index which should replace daylight factors as the metric for daylight design.
Glare	Direct sunlight or bright daylight can cause glare, which can create visual discomfort, or make it difficult to see computer monitors clearly. Pulling blinds down is the usual method of controlling glare, but this also reduces daylight and views, and in naturally ventilated buildings can impede air flows through open windows.	Split venetian blinds with high and low level adjustment to control glare while still allowing daylight to enter at high level can be used. Perforated blinds can reduce glare while still allowing views out.[9]
Solar gain	Solar energy entering through the façade will heat up the space and can create local discomfort to occupants seated near the façade. The solar gain is different on each façade orientation due to the path (angle) of the sun. This is a complex issue, often requiring modelling to quantify the radiant temperatures and resulting internal heat gains. Solar gain in winter can be useful in some buildings (e.g. houses which store heat during the day and release it into the space at night), but in most office buildings the low level winter sun can cause glare.	Solar gain can be reduced by: • limiting the area of glazing • using a solar control glass (or film) • external shading • internal reflective blinds. An integrated design process, taking daylight and views into consideration, is required to develop an appropriate solution on each façade orientation. Since 2010 the UK building regulations include a requirement to limit solar gain through each façade between April and September. Refer to section H3.7 for more details.
Insulation	The level of insulation required will depend on the type of building and the climate. In cold climates, thick insulation and double/triple glazing is used to reduce heat loss. In hot climates, insulation becomes less critical, and providing too much can increase the cooling energy required to get rid of the trapped heat, particularly if mechanical ventilation and/or comfort cooling is used.	In the UK, the 2010 Building Regulations require U-values in office buildings to be not greater than: W/m^2.K Windows 2.2 Walls 0.35 Roof 0.25 Ground Slabs 0.25
Air permeability	This is the uncontrolled movement of air (leakage) through gaps and cracks in the façade, causing heat loss in winter and heat gain in summer, as well as potential discomfort (draughts) for occupants.	New office buildings should really be designed to achieve a maximum 5 m^3/hr.m^2@50Pa, with less than 3 readily achievable with careful construction. This requires the sealing of all gaps and cracks and taping of joints in vapour barriers.

	Issues	Potential low energy response
Thermal bridging	Thermal bridging occurs when a conductive building component, such as a steel lintel, window frame, glazing mullion or balcony spans the gap between the inside and outside of a building, bypassing the insulation. This creates a path for heat to be conducted through the façade, and also creates cold or hot surfaces which can lead to local discomfort. Cold surfaces in an otherwise warm space can cause condensation, which can lead to damage to finishes and/or mould growth.	Building regulations are increasingly becoming more stringent on the reduction of thermal bridging, and there are now many standard details and proprietary products available. In particular, window frames and mullions should be thermally broken.
Cold surfaces	In winter, the internal surface of glazing or poorly insulated walls can become cold. This can create discomfort to occupants sitting near the façade (they radiate body heat to the cold surface). Consequently, to feel comfortable the air temperature needs to be higher, which increases energy consumption. This is either through heating the whole zone to a higher temperature or via local heating (such as plugging in an electric convector heater under the desk). This local impact is often missed in energy models, which usually suggest that less heating is required than occurs in practice.	Improving the insulation properties of the façade (U-value) will improve comfort in winter as well as reducing energy consumption. Low-e coatings can increase the surface temperature of glazing.
Natural ventilation	The ability to naturally ventilate depends on a variety of factors, including: • climate • building depth • height of building • internal heat loads (including solar gain) • external noise • thermal comfort criteria (refer to section 6.2). If the building is built as a sealed box then natural ventilation will not be possible in the future without major modifications to the façade.	Provide openable windows whenever possible, with high and low level openings. A typical rule of thumb is to provide an evenly distributed free ventilation area not less than 5% of the floor area (more in warmer climates) – refer to section H.4. Limiting solar gain and internal heat loads are essential to make natural ventilation work, usually in conjunction with thermal mass.
Noise	Noise is unwanted sound. Background noise is not always a bad thing and can help mask conversations or other residual noise. If external noise (from roads, railways, etc.) is significant then this can lead to distraction and lower productivity in offices. Glass is not as efficient a noise attenuator as other external façade elements, therefore a large air gap in double glazing or thick glass is required in noisy environments.	Providing natural ventilation in noisy environments is not easy. Openable windows have very limited acoustic attenuation – let in the air and you also let in noise. Introducing bends in the air path such as through ventilation louvers with absorptive material can cut down noise, but also reduces air flows. Adding a second skin (double façade) is another, often expensive, solution. There is also a risk with double facades of introducing noise flanking between adjacent floors of the building via open windows. Defining which noise levels are acceptable can have a big influence on the façade and ventilation strategy.

Table H.3 Summary of facade issues and potential responses

Fig H.7 **Full height glass doesn't always look great when occupied (photo: author)**

H3.3 Thermal imaging surveys of building facades

Thermal imaging is a useful method to identify where heat losses are occurring in the façades of existing buildings due to: missing or inadequate insulation; thermal bridging; air leakage; and moisture ingress. Moisture is an efficient conductor of heat energy and so wet insulation can be worse than no insulation.

Figure H.8 shows typical thermographic images of building facades. The red areas show where heat is leaking out of the building. The images must be taken at night to avoid distorted results due to the sun heating the façade.

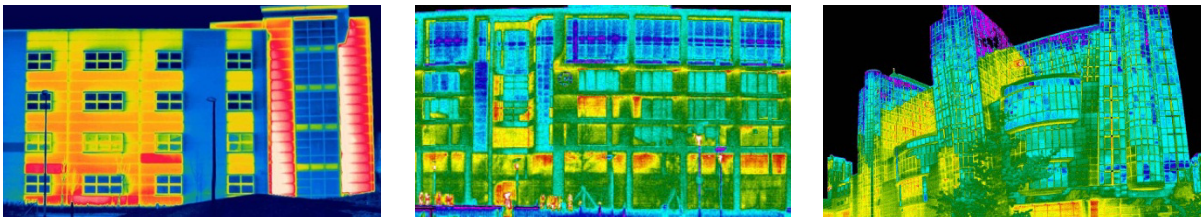


Fig H.8 **Use of thermography to assess thermal performance of existing facades (source: IRT Surveys)**

GLASS PROPERTIES

The key properties of glazing that affect selection from a thermal and daylight perspective are:

- **U-value** – the heat loss through conduction.
- **g-value** – also known as the Solar Heat Gain Coefficient (SHGC), this is the proportion of solar energy that is transmitted through the glazing.[10]
- **Visible Light Transmission** (VLT) – the amount of visible light transmitted through the glazing, sometimes referred to as the t-value.
- **Reflectance** – the amount of visible light reflected (can cause glare problems outside the building).

H3.4 Current and historic fabric performance requirements in UK building regulations

Table H.4 shows some typical U-values and air permeability requirements in the UK building regulations since the 1950s. These values may be useful when seeking to improve the performance of existing buildings where details of the installed insulation are not available. The PassivHaus standard is shown for comparison.

It is important to note that using the latest backstop U-values does not mean that the building will achieve the Target Emissions Rate in $kgCO_2/m^2$ to pass Part L building regulations, and further improvements may be required, depending on the configuration of the building, area of glazing, etc.

	Glazing	Wall	Roof	Floor	Air tightness
	$W/m^2.k$				$m^3/h/m^2$ @ 50 Pa
UK – Part L					
1958	-	1.7	-	-	-
1965	5.7	1.7	1.42	-	-
1974	5.7	1.0	0.6	-	-
1985	5.7	0.6	0.35	-	-
1990	5.7	0.45	0.25	0.45	-
1995	3.3	0.45	0.25	0.45	-
2002	2.2	0.35	0.25	0.25	-
2006 & 2010	2.2	0.35	0.25	0.25	10
PassivHaus					
UK 2012	0.85	0.15	0.15	0.15	0.6

Table H.4 Maximum (backstop) U-values and air tightness in the UK building regulations

H3.5 Heat loss – insulation and infiltration

A typical rule of thumb for heating system sizing in UK office buildings is 70 W/m^2. Figure H.9 shows the heat loss for a temperature difference of 25°C in a 2 storey office building (50 m x 15 m x 7 m high) designed to Part L 2006 U-values with an air permeability of 10 $m^3/hr/m^2$. The façade has 75% glazing and an occupancy of 1 person per 15 m^2 is assumed with a fresh air rate of 10 l/s/person. The calculated heat loss is 66 W/m^2, which correlates reasonably well with the rule of thumb. The glazing accounts for 50% of the heat loss and the heating of the fresh air supply for 30%.

If the air tightness was improved to 5 $m^3/hr/m^2$, a 70% efficient heat recovery system was installed on the fresh air supply, and a glazing unit with a U-value of 1.8 was used, then the heat loss would reduce to 43 W/m^2. Reducing the glazing area to 40% of the façade area (not shown in Figure H.9) further reduces the heat loss to 32 W/m^2, half that of the rule of thumb typically used for heating system design in the UK.

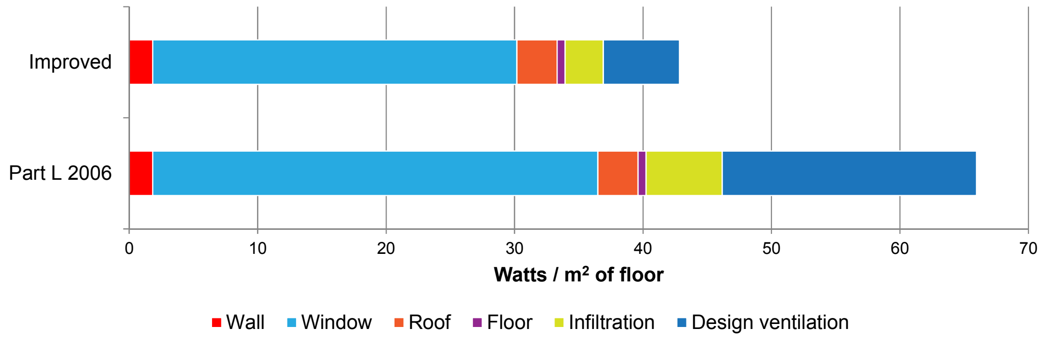


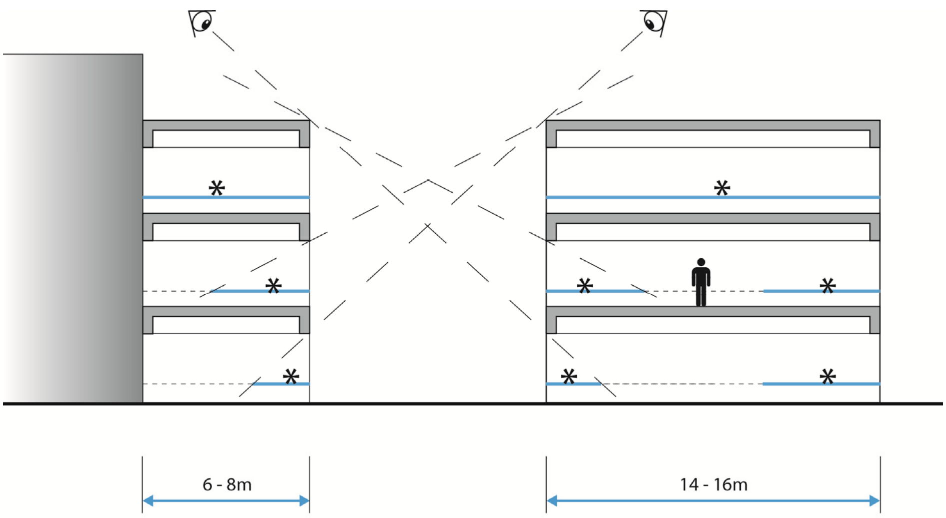
Fig H.9 **Heat losses in a 2 storey office building (delta T = 25°C)**

H3.6 Daylight

Daylight and views are very important for the wellbeing of building occupants. Research has also shown that the eye uses light not just for visual purposes but also for non-visual, biological purposes: light is a component in the production of Vitamin D (strong bones), in the production of Cortisol (alertness) and the suppression of Melatonin (mood, body clock functions).[11]

As a rule of thumb for daylighting, if you can see the sky from a workstation then you have a fighting chance of getting reasonable daylight at this location. The actual level of daylight will depend on window design, type of glass and reflectance of internal finishes – but the view of sky rule is useful to check the potential daylight before undertaking detailed analysis.

Figure H.10 shows indicative maximum room depths to achieve an average 2% and a minimum 0.8% daylight factor (the BREEAM 2011 daylight target), and how the view of sky limits this. The atrium, while being well daylit at the base, is still too narrow to allow daylight to penetrate much into the lower floors. In 1996, German building regulations introduced requirements for natural light and external views, typically limiting the distance from a workplace to a window to between 6 to 7.5 m.[12]



* Typical maximum room depth which will achieve average 2% DF and minimum 0.8% DF on the working plane

Fig H.10 **'View of sky' rule of thumb for daylighting in office buildings**

Daylight can lead to energy savings by allowing perimeter lights to be turned off – but only if it is useful daylight. To be useful it must not create glare issues (if the blinds are permanently down then daylight is reduced) and be delivered at desk level (daylight on the carpet next to full height glazing is not really useful unless you are sitting on the floor). The traditional design assessment for daylight in buildings, the daylight factor (a percentage of light from a standard overcast sky) is being gradually replaced with the Useful Daylight Index (UDI) which more closely considers real daylight and sunlight conditions throughout the day by using climate-based daylight modelling.[13] It's not always overcast, even in Manchester.

The biggest challenges of bringing daylight into an office building involve doing so without admitting too much heat in summer (solar gain) which would then increase the requirement for cooling, and avoiding glare which results in 'blinds down, lights on'. Both of these can lead to higher energy consumption and/or discomfort for occupants.

H3.7 Solar gain

As discussed in Section 6.2 of Chapter 6, thermal comfort is not just related to air temperature. Even if the air conditioning system can maintain the design air temperature, this doesn't mean that the occupants will be comfortable. Radiant heat has a major influence on comfort, but this is often not incorporated into building design briefs. Anyone sitting near a cold glass surface or in direct sunlight will have a different experience to someone in the same space a few metres away. This issue needs to be considered from the outset, otherwise the facility manager will spend the next 20 years trying to juggle the differing comfort complaints in the building by adjusting the only control variable available to them – the supply air temperature set point.

In the UK, Part L of the Building Regulations 2010 introduced a new Criterion 3 for limiting solar gain in buildings to reduce cooling energy consumption. It states that any space that is occupied and/or air conditioned must have a solar gain that does not exceed a stated limit. The limiting value, which applies to every façade in the building, is set by calculating the total solar gain between April to September through an eastern facade which has a 900 mm glazed section with a g-value of 0.68 as shown in Figure H.11. This represents about 33% glazing to façade area for a floor to ceiling height of 2.7m.

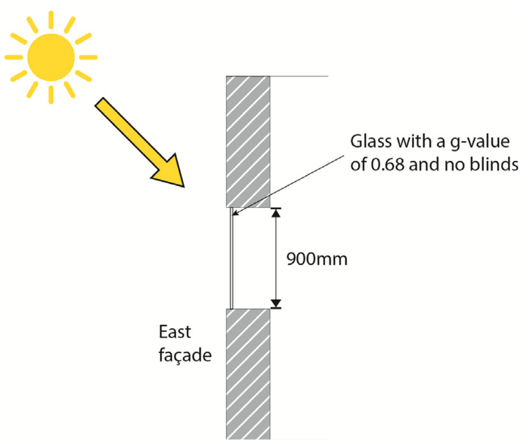


Fig H.11 Solar gain limit calculated based on kWh through east façade glazing (April to September)

If this configuration was used on the west façade, it would fail due to higher solar gains. To meet the criteria, the façade designer has a number of variables to play with:

- the area of glazing
- the g-value of the glass
- external shading – fixed or operable
- internal blinds.

These can, and arguably should, be different on each orientation to suit the different solar loads. Reducing the area of glazing, providing external shading and reducing the g-value of the glass will all typically reduce daylight. The art of good façade design is getting the balance right.

CHANGING THE PROPERTIES OF GLASS DURING THE DAY

Various switchable glazing technologies are being developed which alter the light and solar transmission properties of the glass when a low voltage is applied. They allow solar gain to be reduced when in direct sun by darkening to a coloured state, and can be switched to be clear at other times to maximise daylight. The electrochromic versions require a short electric impulse to change from clear to coloured and back again (with various steps possible in-between).[14] Capital costs are currently high (around 550-650 €/m^2) but should become more affordable in the future.

An example of electrochromic glass is EControl-Glas manufactured in Germany – refer to figure H.12. The standard double-glazed unit is 29 mm thick, consisting of 9 mm electrochromic pane (outer surface), 16 mm cavity and 4 mm inner pane with low-e coating. One complete switching cycle requires less than 1.5 W/m^2.

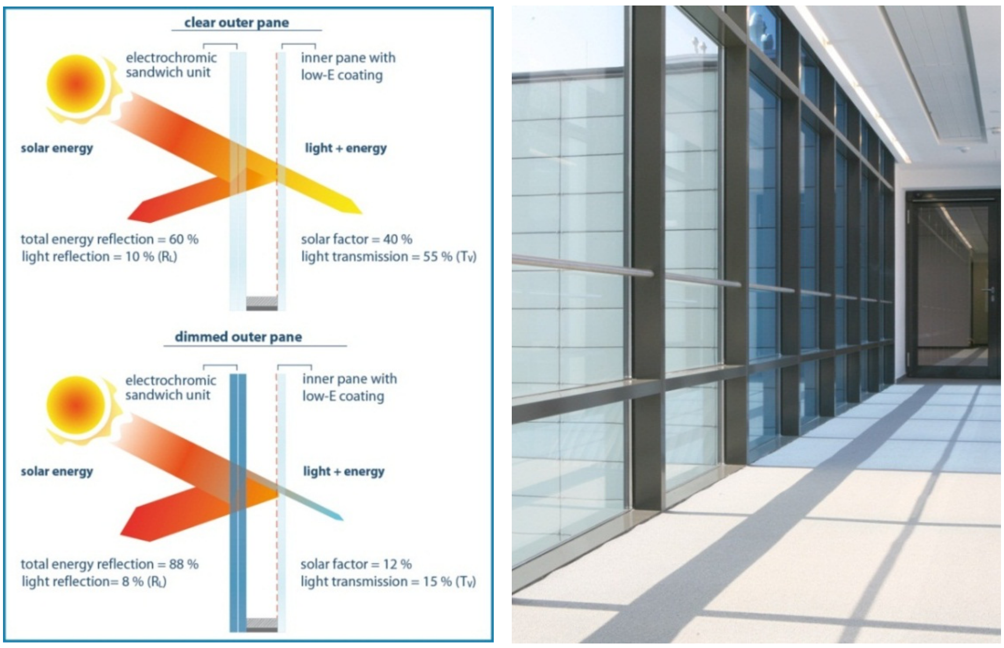


Fig H.12 Example switchable solar control glazing (source: EControl-Glas GmbH)

H3.8 Glare

In addition to controlling solar gain, blinds are also used to control glare. While solar gain can be readily estimated, predicting glare is not straightforward. Figure H.13 shows sun streaming in through the west-facing windows of an office at 8 am in Melbourne. This was due to the sun reflecting off the glazed façade of a high rise office one city block away. While this only occurs occasionally during the year, it illustrates the challenge of predicting glare. Another example is sunlight reflecting off the windscreens of cars parked next to ground floor office windows.

Fig H.13 Glare through west-facing windows at 8 am – Melbourne office on 23 October 2006 (photos: author)

Numerous glare metrics exist, but these are primarily focussed on predicting glare from artificial lighting. The difficulty with calculating glare from daylight is that it is highly dependent on an occupant's position and view direction, and is constantly changing (the sun keeps moving).

The Daylight Glare Probability (DGP) Index, initially proposed in 2006, is a metric which represents the percentage of people likely to be disturbed by glare, and is based on human reactions to daylight-based glare in side-lit office environments with venetian blinds.[15] Further development of the metric, and incorporation into daylight modelling software, may result in this metric being more widely used.

H3.9 Impact of façade on HVAC design

While the facade has little impact on the performance of the internal zones, it does have a major impact on the design of the HVAC systems in the perimeter zone, which is typically 4.5m deep.

If the heat gains from people, equipment and facade exceed the cooling capacity of a particular HVAC system (refer to Table H.5) then that system cannot be used in the perimeter zone. For example, displacement systems require much better facades than fan coil units. Sections H4 and H5 provide more details on HVAC systems.

HVAC system	Typical cooling capacity (W/m² of floor area)
Displacement *	40 to 60
Passive chilled beams (PCB)	80 to 95
Active chilled beams (ACB)	90 to 110
Variable air volume (VAV)	100 to 150
Fan coil units (FCU)	
Variable refrigerant flow (VRF)	
Fan assisted VAV (FAT boxes) **	130 to 200

* depends on height of space
** often used for trading floors

Table H.5 Typical cooling capacity of different air conditioning systems

H3.10 Modelling of façade options for thermal and daylight performance

For this book, Cundall has undertaken a modelling exercise to illustrate the difference in peak cooling loads, thermal comfort and daylight performance (both Daylight Factor and Useful Daylight Index) for a generic range of façade options.[16] The building modelled is in central London with a floor plan of 15m by 50m, a floor to floor height of 3.6m and a ceiling height of 2.7m. The end walls have no glazing, and the daylight and comfort modelling results for the different façade options are for a central slice through the building. Figure H.14 shows the thermal model with nine different façade options and figure H.15 shows the dimensions of each façade option.

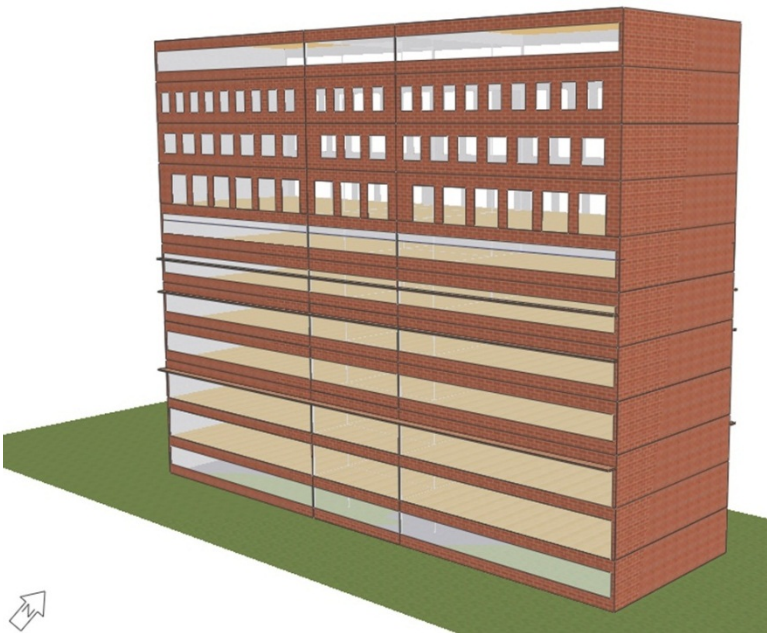
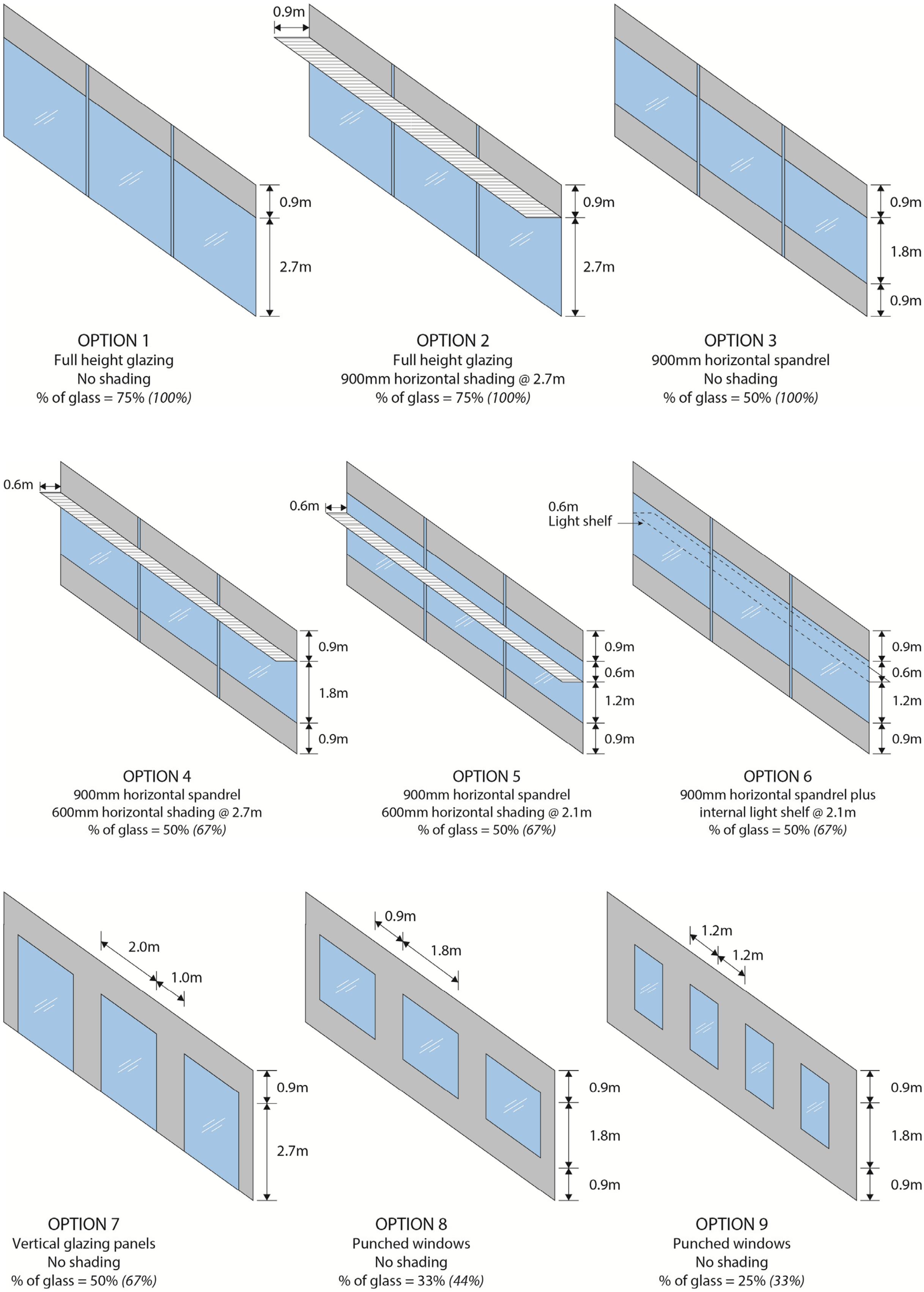


Fig H.14 Thermal model used for comfort analysis



The percentage of glass is based on the floor to floor façade area. The percentage of glass in brackets is based on the floor to ceiling façade area (i.e. the occupied zone).

Fig H.15 Dimensions of façade options 1 to 9

The glazing in all options has the following properties:

- U-value = 1.8 W/m².k
- g-value = 0.33 (0.28 with blinds down)
- t-value = 0.61 (0.24 with blinds down)
- 5% frame to glass area

The solid wall elements have a U-value of 0.35 W/m².k and the façade air tightness is 5 m³/m³/hour. Two iterations of the modelling were undertaken, with the model on a north-south axis and then again on an east-west axis to get results for facades facing north, south, east and west. No external shading was assumed on the north façade.

The daylight was modelled using Radiance software. For the daylight factor, no blinds were assumed. The Useful Daylight Index (UDI) range was set at 100 to 2000 lux (i.e. daylight below 100 lux is insufficient and daylight above 2000 lux was assumed too bright, resulting in blinds being pulled down). Figure H.16 shows the difference in results assessing daylight using daylight factors based on a uniform overcast sky (shown as dotted lines) and the Useful Daylight Index (UDI) based on climate-based daylight modelling (which considers the position and intensity of the sun throughout the year).

Option 1, with full height glazing, has the best daylight factor (scoring daylight points in BREEAM) but the worst useful daylight (because there is too much daylight). Conversely, option 9 with 33% glazed area to the wall area below ceiling level, has the worst daylight factor but the highest UDI. Putting lots of glass in buildings to provide better daylight is a flawed approach. Size isn't everything: it's not how big it is, it's how you use it.

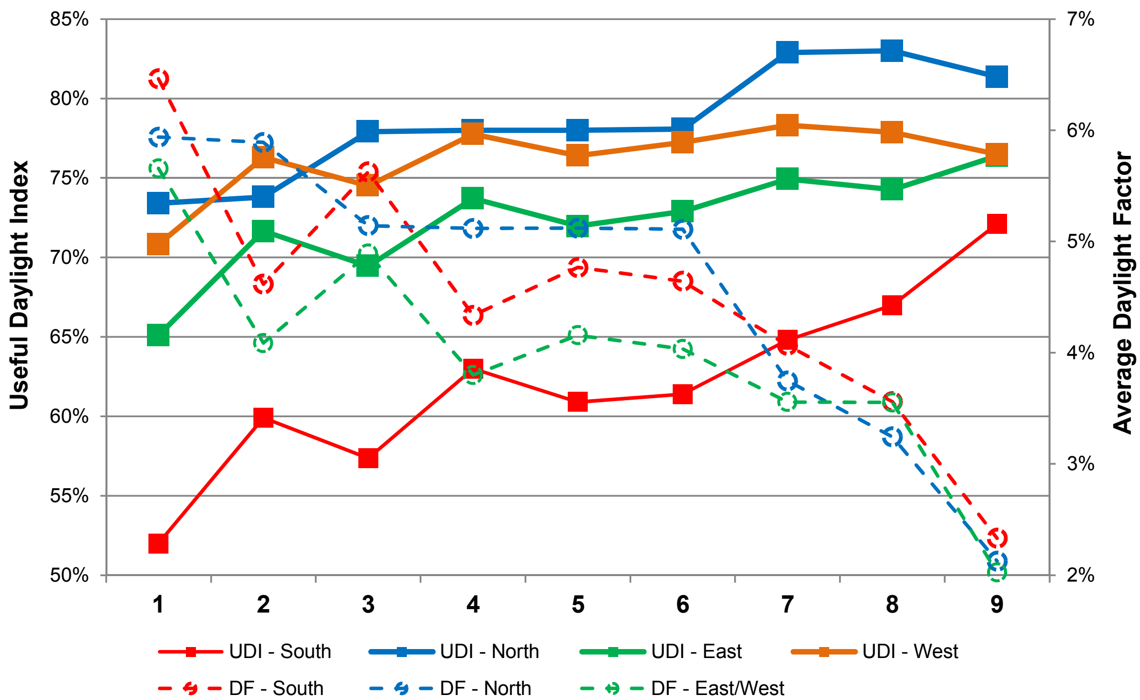


Fig H.16 **Daylight factor (DF) versus Useful Daylight (UDI) in 6 m deep perimeter zone for nine façade options**

Excessive areas of glazing increase the solar gain that impacts on thermal comfort and cooling energy consumption. As glass has a much higher U-value than solid walls (1.8 compared to 0.35) then heat loss through glass is five times greater than through solid insulated walls. To determine the impact of the nine façade options on thermal comfort, the building was modelled in IES software and the following criteria calculated for each façade and orientation:

- % improvement on Part L 2010 criterion 3 (refer to Figure H.11).
- Peak cooling demand (W/m^2) in the 4 m wide perimeter zone with a set point of 23°C for an air conditioned building.
- Peak operative temperature (°C) in the 4 m wide perimeter zone assuming natural ventilation with 2.5% open area on opposite facades.
- No. of hours per annum that the operative temperature exceeds 28°C with natural ventilation.

Figure H.17 summarises the results which all show a consistent trend – option 1 has higher operative temperatures and cooling loads (40°C and 119 W/m^2) than option 9 (32°C and 55 W/m^2).

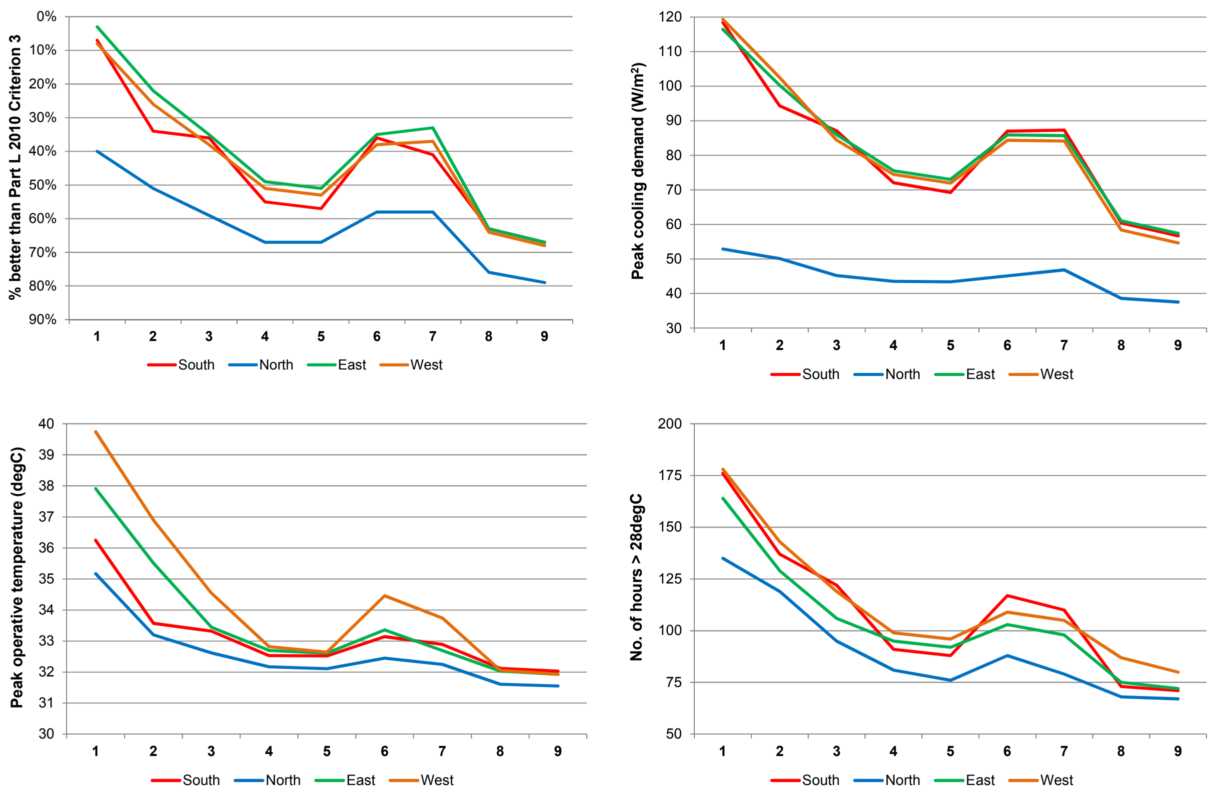


Fig H.17 Thermal comfort indicators for different façade options and orientations

To allow comparison between comfort and daylight for the different options, a comparative score for each has been calculated. The number of hours that the temperate exceeds 28°C is adopted as the proxy for thermal comfort. A score of 0% is given to the highest hours (178 hours for west façade option 1) and 100% to the lowest hours (67 hours for north façade option 9). The score for all other results is based on where they fall within this range.

A similar approach was used for daylight within the first 6 m of the façade, with a score of 0% for least daylight (52% for south façade option 1) and 100% for the most daylight (83% for north façade option 8).

Figure H.18 shows the combined average of the comparative scores for the north, south, east and west orientations for each façade option. Figure H.19 (overleaf) shows the comparative scores for each option and orientation – the further from the centre the higher the thermal comfort and useful daylight.

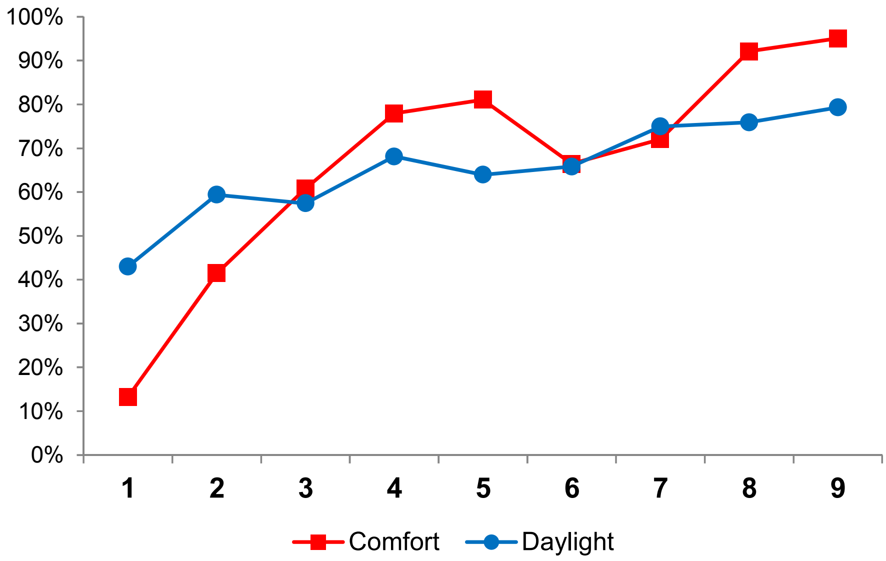
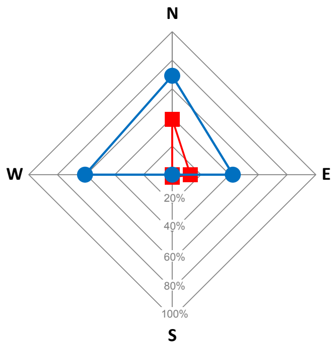


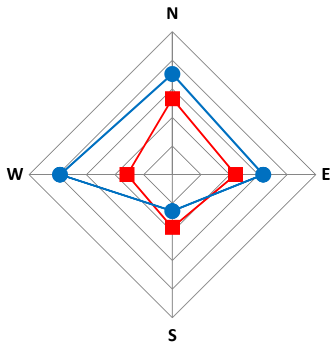
Fig H.18 Average thermal comfort and daylight comparative scores for nine façade options

Can a fully-glazed building really be considered to be low energy, even if a lot of money is spent on high performance glazing and shading systems? From this analysis it appears difficult to justify fully-glazed facades from an energy, comfort or daylight perspective. This is not to say that wall to ceiling glazed panels shouldn't be used, but that they should be used more imaginatively to frame views while still delivering reasonable daylight and comfort.

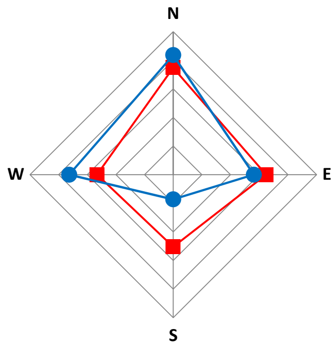
A ratio of 50% glazed to solid area is a good starting point when considering the design of a façade.



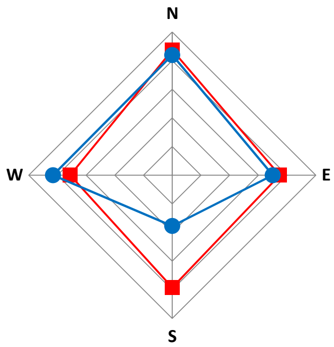
Option 1
Full height glazing
No shading
% of glass = 75% (100%)



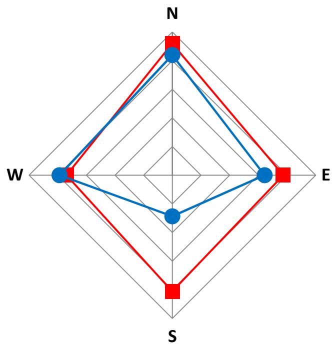
Option 2
Full height glazing
External shading @ 2.7m
% of glass = 75% (100%)



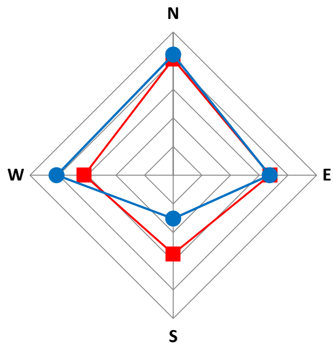
Option 3
900mm horizontal spandrel
No shading
% of glass = 50% (67%)



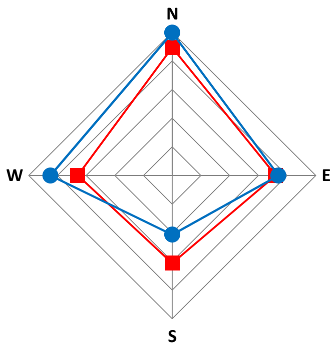
Option 4
900mm horizontal spandrel
External shading @ 2.7m
% of glass = 50% (67%)



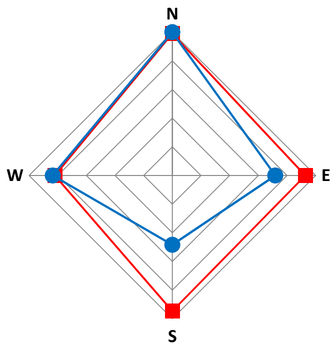
Option 5
900mm horizontal spandrel
External shading @ 2.1m
% of glass = 50% (67%)



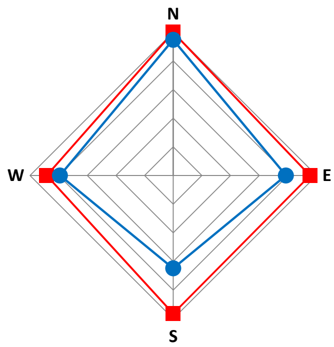
Option 6
900mm horizontal spandrel
Internal light shelf
% of glass = 50% (67%)



Option 7
Vertical glazing panels
No shading
% of glass = 50% (67%)



Option 8
Punched windows
No shading
% of glass = 33% (44%)



Option 9
Punched windows
No shading
% of glass = 25% (33%)

Fig H.19 Thermal comfort and daylight comparative scores for different façade options

CASE STUDY: 55 ST ANDREWS PLACE, MELBOURNE

The upgrade of 55 St Andrews Place in Melbourne's Treasury Reserve, a 6,000 m^2 government building, was completed in 2007. The aim of the project was to transform a poorly performing building into a building that achieved best practice for the occupants, from both an energy efficiency and indoor environment perspective. The approach adopted was to go back to first principles and consider the same issues as if a new building was being designed, to: improve daylight; improve comfort and air quality; reduce solar heat load entering the building through the roof and windows; and retain existing materials, systems, appliances and other equipment where possible.

The majority of the building's windows face east and west and receive large solar gains. As they were not shaded, the resultant internal heat gain required a lot of energy to cool. To reduce the solar gain through the windows, the existing glass had been heavily tinted and a reflective film had also been applied. Consequently, very little daylight entered the building. The windows also got very hot, which meant that anyone sitting next to the windows was uncomfortable when the sun was shining on them. A number of these also cracked due to thermal stresses.

To increase the daylight potential, improve comfort and reduce air conditioning loads, the glazing on levels 1 to 3 was replaced with clear low-e glass, and external automated daylight guidance blinds were installed to control the solar load before it entered the building (refer to Figure H.20). The blinds allow for adjustment in two high and low level panels – allowing for glare to be avoided at desk level, and light to be reflected up to the ceiling at the same time. Each window has a manual override switch to give users direct control.


Fig H.20 55 St Andrews Place, Melbourne with external automated daylight guidance blinds (photos: author)

On Level 4 the large expanse of full height tinted glazing in the office area was replaced with an insulated 1.2m high spandrel panel and new low-e glass. This reduced heat losses and gains through the façade, improved comfort and increased daylight levels. The existing full height glazing to the ground level was retained as this had good shading due to the building overhang (and the budget did not allow for total replacement of this glazing).

Due to the improvements in façade performance, daylight and comfort were improved and energy consumption was reduced, while most of the original mechanical systems and ceilings were retained. A host of other initiatives relating to task lighting, materials, improving air quality and water conservation were also undertaken. The design solutions were simple and cost effective with a total cost of under A$800/$m^2$ (£400/m^2) to improve the base building.

H4. VENTILATION

H4.1 UK Building Regulations

In the UK, Part F of the Building Regulations 2010 has the following requirements for fresh (outside) air supply in office buildings:

- Mechanical ventilation: 10 l/s/person (no smoking or significant pollutant sources).
- Natural ventilation: compliance with CIBSE AM10: *Natural ventilation in non-domestic buildings.*

It is unfortunate that building regulations and rating tools have often provided little encouragement for naturally ventilated or mixed mode systems. For example, the 2006 version of BREEAM used Part L Building Regulations to benchmark energy. At the time it was easier to score energy points for air conditioning than it was for natural ventilation.

AIR CHANGES PER HOUR

Ventilation rates are often expressed in air changes per hour (ach). To calculate this, first convert l/s to m^3/hr by multiplying by 3.6. A minimum fresh air rate of 10 l/s/person therefore becomes 36 m^3/hr/person.

Next calculate the volume of a space and the number of people in it. A 100m^2 space with a ceiling height of 3 m has a volume of 300 m^3. If there are 10 people in the space, the minimum fresh air required is 36 x 10 = 360 m^3/hr and the air change rate is 360/300 = 1.2 ach.

H4.2 Natural ventilation requirements in BREEAM 2011

The BREEAM New Construction 2011 Technical Manual describes two methods to demonstrate adequate natural ventilation in an office space:

- **Minimum area of openable windows**
  A minimum 5% of the gross internal floor area. For spaces 7 to 15 m deep, the openable window area must be on opposite sides and evenly distributed to promote adequate cross-ventilation. This method cannot be used for spaces greater than 15 m deep.
- **Design Calculations**
  Demonstrate that adequate cross flow of air is provided to maintain required thermal comfort conditions and ventilation rates using ventilation design tool types recommended by CIBSE AM10.

For both approaches, the natural ventilation strategy must provide user control for the supply of fresh air to the occupied space, as follows:

- **Higher rate:** higher rates of ventilation to purge short-term odours and/or prevent summertime overheating.
- **Lower rate:** adequate levels of draught-free fresh air to meet the need for good indoor air quality throughout the year, sufficient for the occupancy load and the internal pollution loads of the space.

Opening mechanisms must be easily accessible and provide adequate user control over air flow rates to avoid draughts.

H4.3 Internal heat gains

The capacity of natural ventilation to remove heat in a building in the UK is typically assumed to be around 40 W/m^2. This capacity can be exceeded by internal heat gains alone, before any solar gain through the façade is taken into account. Table 6.2 of CIBSE Guide F gives internal heat loads (W/m^2) in offices for different occupancy densities – refer to Table H.6.

Use	m^2 per person	Light	Equipment	People (sensible)	People (latent)	**TOTAL (with efficient lighting)**
		W/m^2				
Meeting room	3	10 - 20	5	27	20	**62**
Call centre	5	8 - 12	60	16	12	**96**
City Centre	6	8 - 12	25	14	10	**57**
City Centre	10	8 - 12	18	8	6	**38**
General	12	8 - 12	15	7	5	**35**
General	16	8 - 12	12	5	4	**29**

Table H.6 Typical internal heat loads (source: Table 6.2 of CIBSE Guide F)

H4.4 Making natural ventilation work

The following guidelines can improve the effectiveness of natural ventilation in office buildings:

- Provide good quality windows, evenly distributed along the façade.
- Maintain open/closing mechanisms and seals.
- Upper openings can be automated to allow auto-operation and night purging of any exposed thermal mass. In an open plan office, typically only 1 in every 4 openings need to be automated for night purge.
- All automated controls should have manual override.

- Avoid automating lower openings – these can cause discomfort to occupants (and blow all the papers off desks if opened on a windy day).
- Consider simple temperature or CO_2 indicators to tell occupants when to open windows instead of automating them.
- Blinds should be designed to not impede air flows.
- Use high level openings or trickle ventilators to provide fresh air in winter while avoiding cold draughts (or consider mechanical ventilation with heat recovery in winter – the PassivHaus approach).
- Provide separate extracts for equipment with high heat outputs (e.g. server racks, photocopiers) to reduce internal heat gain in the office space.
- Utilise exposed thermal mass (typically an exposed concrete slab soffit) to reduce peak internal temperatures by up to 5°C and provide up to 50 – 60 W/m^2 of cooling capacity.[17]

H4.5 Barriers to natural ventilation

A study by University College London[18] in 2011 found the following barriers to using natural ventilation in new buildings in the UK:

- perceived as too complex
- too unconventional
- limited to specific conditions
- decision makers have no financial incentive
- capital cost of switching over too high
- poor collaboration across the supply chain
- lack of knowledge
- procurement, specifications and liability structure tailored for HVAC
- users fear unreliability of natural ventilation
- thermal comfort criteria set too high.

The fact that building regulations and environmental rating tools provide few incentives could be added to this list. Clearly all of these barriers need to be tackled if the industry is to move towards mixed mode or naturally ventilated buildings in the future.

H4.6 Open windows don't result in instant death!

There is often a misconception that openable windows in offices have to be limited to a 100 mm opening using restrictors, otherwise people will simply fall out. Where did this assumed limit come from? There are a number of relevant building regulations and British Standards governing window openings:

- Part K (Protection from falling) has a requirement to prevent people outside the building from walking into openable window frames projecting more than 100 mm beyond the face of a building where they are within 2 m of the ground. Any windows above ground floor (and high level windows on ground floor) are therefore not affected. Landscaping or barriers around the perimeter of the building to stop people walking into ground floor windows can be used instead of restricting the opening – or inward opening windows on the ground floor can be used.
- BS 8213 takes a risk management approach to prevent people falling out of windows, primarily aimed at residential buildings. There is no specific requirement to fit restrictors. Annex B suggests that where safety restrictors are fitted, they '*shouldn't be able to be overridden to open more than 100 mm by under-5 year olds*.' Most office workers are smarter than 5 year olds.
- Workplace (Health, Safety & Welfare) Regulations 1992 have regulations regarding safety of glazing in the case of breakage, the ability to clean windows safely, and that the operation or location of windows should not expose people to risks to their health and safety. There are no stated requirements for restrictors.

So the reality is that there is really no legal restriction on how much windows can open in an office building – just apply common sense. The exception is ground floor windows below 2 m, and security considerations may also dictate that windows here should not be allowed to open too much.

H4.7 Natural ventilation design and operation

The detailed design of natural ventilation systems is too complex to explore in this book. For further guidance on natural ventilation design and operation, refer to:

- *Natural ventilation in non-domestic buildings*, CIBSE AM10 (2005).
- CIBSE AM10 Design Tool: www.cibse.org/docs/AM10CalcToolv5.xls.
- *The Illustrated Guide to Ventilation*, BSRIA Guide 2/2009.
- *Fundamentals*, ASHRAE Handbook 2009.
- *Natural Choice: Lessons learned from low carbon buildings with natural ventilation*, Carbon Trust Guide CTG048, 2011.

CASE STUDY: BUTTERFIELD INNOVATION CENTRE, LUTON

The Butterfield Innovation Centre, located in a business park in Luton, is a 2 storey naturally ventilated office building for start-up technology companies. Figure H.21 shows the strategies employed to naturally ventilate the building and maintain thermal comfort.

Fig H.21 Natural ventilation strategies at Butterfield Innovation Centre, Luton (photos: author)

H4.8 Noise and ventilation openings

Noise is unwanted sound, and can have a detrimental impact on productivity and creativity in the workplace. Acoustic problems and disturbance in a room are often derived from either long reverberation times, which give a room an 'echoey' feel (too many hard surfaces), or from noises outside the room (transferred through the façade or from adjacent rooms).

Noise primarily affects the energy performance of buildings through its influence on the ability to utilise natural ventilation and thermal mass:

- Limits to openable windows/louvers due to external noise.
- Reverberation caused by too much exposed thermal mass.
- Partitions between internal spaces preventing or restricting natural air flows.

None of these problems are insurmountable, but generally once significant attenuation is required then natural ventilation is either not going to work (too much air resistance) or the solutions become so expensive that it becomes unaffordable. In mechanically ventilated buildings, acoustic attenuation of air ducts can increase air resistance, resulting in increased fan energy consumption.

BREEAM 2011 requires that offices do not exceed 'good practice' indoor ambient noise levels stated in BS 8233:1999: single occupancy offices ≤ 40dB LAeq,T and multiple occupancy offices 40 to 50dB LAeq,T.

It is worth noting that if offices are made too quiet then there can be issues with privacy as conversations are not masked by background noise. Where privacy is not deemed to be an issue by the final occupier, the lower limit of the range can be disregarded and the upper level criterion is 50dB LAeq,T.

SOUND PRINCIPLES

Sound is a series of waves or pressure fluctuations, which start with an object vibrating. It moves or propagates in the air from its source at 343 m/s (768 mph). As it travels, the sound dissipates. If it hits a hard surface, it can be reflected, which can lead to a build-up of sound energy. If it hits a porous surface, the sound is absorbed, with a proportion of the energy changing into heat and the reflected level decreased. As the sound encounters solid objects such as walls, the energy passing through them is reduced.

Sound is measured in terms of the frequency of the wave, expressed in Hertz (Hz), the wavelength (measured in fractions of a metre), and the pressure level, expressed in decibels (dB). Decibels are a logarithmic scale, and are best described using typical noises, e.g. shouting (80 dBA) or a pneumatic drill (100 dBA). Humans can detect a difference in noise levels of about 3 dB. We perceive an increase of 10 dBA as a doubling of loudness. To communicate effectively, normal speech needs to be between 10 dB and 15 dB above the background noise level.

Adapted from 'A Guide to Office Acoustics' by the Association of Interior Specialists (www.acousticguide.org)

H4.9 Fan efficiency and sizing

The most energy efficient fans today comprise an impellor with low aerodynamic losses connected directly (i.e. not via a belt) to brushless direct current (DC) motors, also known as electronically commutated motors (EC motor), with an integrated frequency converter for variable load control. These should have an energy efficiency of between 60 and 80%, depending on size and configuration.[19] For large fans, where EC motors are not yet available, an efficient AC electric motor can be used with a variable frequency drive.

In most existing buildings fans are not energy efficient. A study of 767 fans in existing HVAC systems in Sweden between 2005 and 2009 measured the average total efficiency of all the fans at only 33%.[20]

The *Non-Domestic Building Services Compliance Guide*, which accompanies the UK Part L 2010 Building Regulations, gives maximum specific fan powers in air distribution systems in new and existing (refurbished) buildings. These vary from 1.4 to 2.2 W per l/s for different types of zoned HVAC systems. Local extract systems and fan coil units have a limit of 0.6 W per l/s.

The European Commission Regulation (EC) No 640/2009 set minimum efficiency requirements for new motors from 2011, with more stringent requirements being phased in from 2015. The required efficiency varies, depending on motor size and number of poles, between 75 and 95%.

It is important to select a fan which has optimum efficiency at the typical operating load, which in variable flow systems is often at part load. Fans of different diameters and motor size can provide the same air flow and pressure, but may do so with different efficiencies. One may be more efficient at peak load while another may be at part load.

It is also not uncommon for margins of safety to be added when calculating motor sizes. If a motor is required to deliver 7.5 kW of power then the design engineer may add a 10% margin just to be safe and specify an 8.2 kW motor. The contractor's engineer, unaware of the actual calculated value, takes the 8.2 kW and adds another 10% contingency to get 9.1 kW. The nearest motor size is 11kW so this is selected, when a 7.5 kW motor would have done the job. The 11 kW motor then operates at 68% capacity at full fan load. If the fan is part of a variable speed system and requires the air volume to be turned down, the motor may operate inefficiently for most of the time at less than 40% capacity.

Designing for peak loads only (sizing and efficiency) can often result in increased energy consumption throughout the rest of the year. Annual energy consumption is based on performance every day, and not what happens on the hottest or coldest day of the year.

FURTHER GUIDANCE

- *Non-domestic Building Services Compliance Guide*, 2010 edition, HM Government, UK.
- *Improving Fan System Performance: a sourcebook for industry*, U.S. Department of Energy, Energy Efficiency and Renewable Energy, 2003.

H4.10 Reducing restrictions to airflow

Figure H.22 shows the typical items which provide resistance to air flow or cause turbulence, creating pressure drops, and consequently increasing the power of the fan required to move air around the building. To minimise pressure drops:

- Make the duct sizes as large as possible (and with an aspect ratio as close to square / circular as is feasible).[21]
- Avoid squeezing AHU sizes to the minimum.
- Limit the number of sharp bends and abrupt transitions in size.
- Keep the length of duct to a minimum.
- Ensure ducts are well sealed to reduce air leakage.
- Don't put fans or silencers close to bends or inlets, and install air vanes to reduce turbulence.
- Provide bypass of heat recovery systems.
- Regularly clean air filters and ducts.
- Use plenum boxes to reduce air velocity at diffusers.

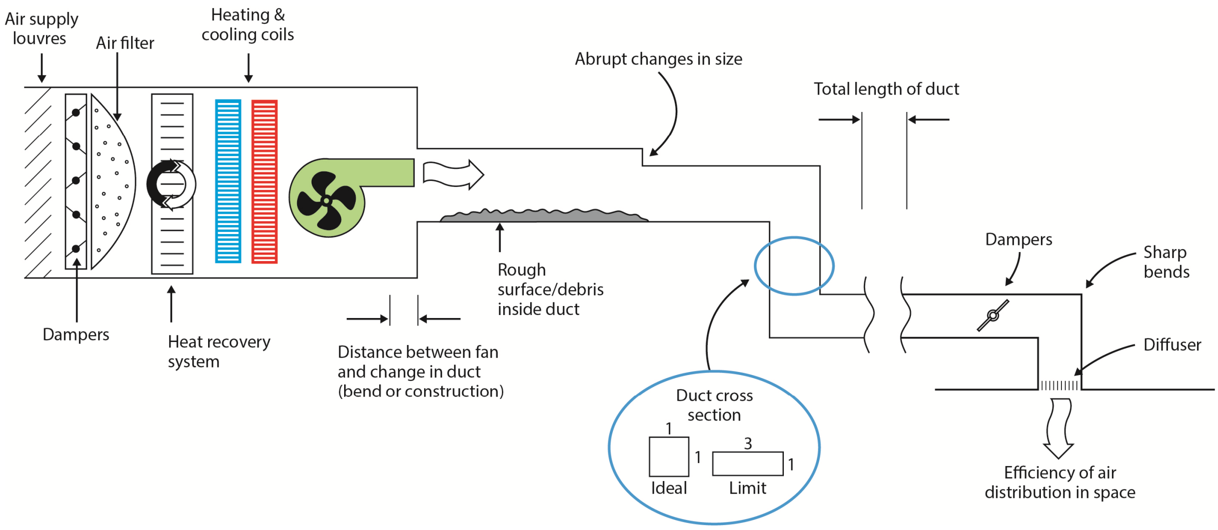


Fig H.22 Restrictions to air flow leading to increased fan consumption

H4.11 Sick building syndrome in mechanically ventilated buildings

CIBSE Guide A (clause 8.4.7) references an American study in 1996 which looked at associations between environmental factors and work-related health conditions in 80 office buildings. This found that the risk of reported respiratory symptoms increased by a factor of:

- 3 times if debris lay in the air supply ducts or there was poor drainage from the air handling unit condensate pans.
- 2 times if air filters were dirty or badly fitting, or if the fresh air inlet was within 8 m of an exhaust air outlet, a toilet exhaust ventilator outlet or a rubbish store.

To reduce these risks locate the air intake away from sources of external pollution (20 m is recommended but often difficult to achieve in practice), clean the filters regularly, and periodically clean the ductwork.

KEEPING IT CLEAN

An office building in 2005 in Australia had been experiencing issues with air quality and temperature control for some time. After investigation the problem was found – a large section of duct insulation in the supply air duct had disintegrated near the air handling unit, and the fibres were then blown throughout the system, clogging up the heating coils in the VAV boxes on all floors. Figure H.23 shows a typical coil – it's amazing the system worked at all! Fortunately, the fibres were found to not have long-term health impacts, otherwise the consequences could have been much more severe than some overheating and stuffiness.

Fig H.23 A not so clean VAV heating coil

H4.12 Ventilation effectiveness

Ventilation effectiveness is the proportion (%) of the fresh air delivered to a space that reaches the occupied zone. It is influenced by numerous factors including the type, spacing and position of supply diffusers and exhaust grilles, and can influence energy consumption as well as air quality.[22] Displacement ventilation, where air is introduced at low level (through floor or wall grilles) and exhausted at high level, is often considered the most effective ventilation system as it uses natural buoyancy (hot air rises) to move air through the space and avoids recirculation. Consequently lower air flows are required.

Ceiling-based systems introduce the supply air at high level, mix it with the air in the space and then exhaust it at high level. If this isn't done well then it can create uneven temperatures and areas of stagnation.

Figure H.24 illustrates how a sneeze might travel through office spaces with different supply air systems.

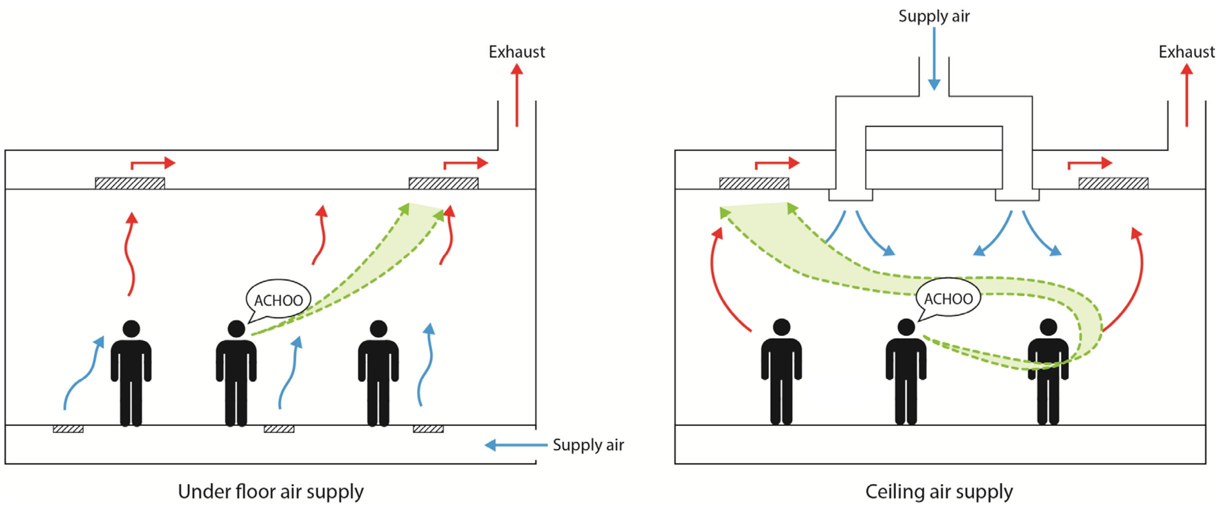


Fig H.24 How a sneeze might be distributed in an office

Ventilation (or air change) effectiveness is not recognised in BREEAM but does score points in Green Star. In naturally ventilated buildings, the criteria relates to the distribution of laminar air flows for at least 95% of occupied hours. For mechanical ventilation, the system must achieve an Air Change Effectiveness (ACE) of >0.95 measured in accordance with ASHRAE 129-1997: *Measuring Air Change Effectiveness*. The ACE is measured in the breathing zone (nominally 1 m from finished floor level).

Prior to 2005, LEED also had a similar credit for ventilation effectiveness, but this was replaced by criteria to increase the fresh air ventilation rate due to practical problems in determining the ACE (which is based on a laboratory standard) using design stage modelling, and during post-occupancy using tracer gas field tests. Green Star also provides points for increasing fresh air rates.

FURTHER GUIDANCE

- *Green Star v3 Technical Manual*, GBCA.
- *LEED Reference Guide for Green Building Design & Construction*, USGBC, 2009.
- *LEED and Standard 62.1* by Steven T. Taylor, ASHRAE Journal, Vol. 47, No. 9, September 2005.
- *Ventilation Effectiveness*, REHVA Guidebook No. 2.
- www.bsria.co.uk/news/ventilation-effectiveness-how-well-do-ventilation-systems-work/

H4.13 Improving controls to save energy

Some simple methods of saving energy in the operation of mechanical ventilation systems include:

- Recommissioning the system to ensure correct air balances and to guarantee that dampers are controlled correctly – it is not uncommon to find economy cycle dampers stuck open (or even wired up the wrong way round).
- Providing localised ventilation units and an out-of-hours switch for each floor rather than for the whole building – if one person is working on one floor, does pressing the out-of-hours ventilation button need to activate the whole building ventilation system?
- Controlling exhausts (e.g. toilets) based on occupancy rather than them being on 24/7 – this not only saves fan energy, but also reduces the extraction of air that has been heated or cooled.
- If the ventilation system is used for heating and cooling then use fully recirculated air (i.e. no fresh/outside air) during pre-heating or pre-cooling prior to occupancy.
- Can CO_2 or PIR-controlled ventilation be introduced to reduce the volume of fresh air required during periods of lower occupancy?

H4.14 Further guidance on mechanical ventilation design and operation

- www.cibsejournal.com/cpd/2012-02/
- *Heating, ventilation and air conditioning: Saving energy without compromising comfort*, CTV046, Carbon Trust, 2011.
- *Heating, ventilating, air conditioning and refrigeration*, CIBSE Guide B, 2005.
- *Energy efficiency in buildings*, CIBSE Guide F, 2012.
- *The Illustrated Guide to Ventilation*, BG 2/2009, BSRIA.
- *The Illustrated Guide to Mechanical Building Services*, AG 15/2002, BSRIA.
- *HVAC Systems and Equipment*, ASHRAE Handbook 2008.
- *HVAC Applications*, ASHRAE Handbook 2011.
- *Fundamentals*, ASHRAE Handbook 2009.
- *Energy savings in fans and fan systems*, GPG383, Carbon Trust.
- *Energy-efficient mechanical ventilation systems*, GPG257, Carbon Trust.
- *Fan application guide*, CIBSE TM42.

OCCUPANT CONTROLLED VENTILATION – TASK AIR

Delivering fresh air directly to occupants working at their desks, without it having been mixed throughout the whole space first, can improve their perception of the indoor air quality. If they also have a degree of control over the flow and direction of air (similar to the vents in a car) then complaints related to thermal comfort in a building will usually decrease. A variety of proprietary systems have been developed to provide workstation-based microclimate control.

One such example is the TaskAir® Workstation[23] which supplies fresh air directly to the occupants through adjustable nozzles incorporated into the workstation screen – refer to Figure H.25. A blade column allows the workstation to be connected directly to a new or existing supply air duct in the ceiling void. The system has been installed in a number of fit-outs in Australia.

Fig H.25 Task Air Workstation – users control volume and direction of airflow (source: UCI / TaskAir)

H5. HEATING AND COOLING

H5.1 Design for typical conditions not just peak

Many building systems are designed to meet peak heating and cooling demand with little consideration for how they work at part load. The peak demand may only occur for a few hours each year, while the heating/cooling systems consume energy for at least 2,600 hours per year (and 8,760 hours if left on 24/7). If a system only works efficiently at the peak load (<100 hours a year) and inefficiently for the remainder (>2,000 hours per year) then this is poor design.

Unfortunately, contractual obligations usually only relate to systems working at peak conditions and so this becomes the key design driver. If the engineers' contracts were linked to ongoing energy performance, different design philosophies would undoubtedly be adopted.

The use of dynamic thermal modelling of buildings can be used to optimise plant sizing and staging strategies at part loads.

H5.2 Reduce demand

Section H3 discussed how the façade's performance influences the heating and cooling energy demand and consumption, including:

- Heat loss through the façade in winter increasing heating demand.
- Solar gain in the summer increasing cooling loads.
- Infiltration (air leakage) through the façade affecting both heating and cooling.

Other methods of reducing internal heat gains in an office space include:

- Installing external daylight guidance blinds to reduce solar gain, but still allowing daylight into the space (enabling perimeter lights to be turned off).
- Installing efficient lighting systems and turning them off when they are not needed.
- Purchasing energy-efficient equipment with low stand-by energy consumption.
- Allowing heat to be displaced to a high level above the occupied zone.
- Utilising thermal mass (or phase change materials) to absorb heat during the day, and providing a method of purging the heat at night – see below.
- Providing, where practical, separate exhaust from high energy equipment, including servers and photocopiers, to avoid these heating up the occupied space (and creating the necessity to cool the whole space).

H5.3 The potential benefit of thermal mass

By absorbing heat energy during the day, thermal mass can be used to reduce internal summer temperatures in office buildings by up to 5°C – refer to Figure H.26. The stored heat must then be removed, usually by natural ventilation of cooler night time air, but other methods (such as cooling water in pipes embedded in a slab) are possible. Thermal mass can deliver up to 20 to 30 W/m^2 of cooling inside a building using natural ventilation (up to 40 W/m^2 in precast hollow core slabs with mechanical ventilation). It was used for centuries before the invention of air conditioning allowed lightweight fully-glazed buildings to become habitable – previously they were only good for growing fruit in.

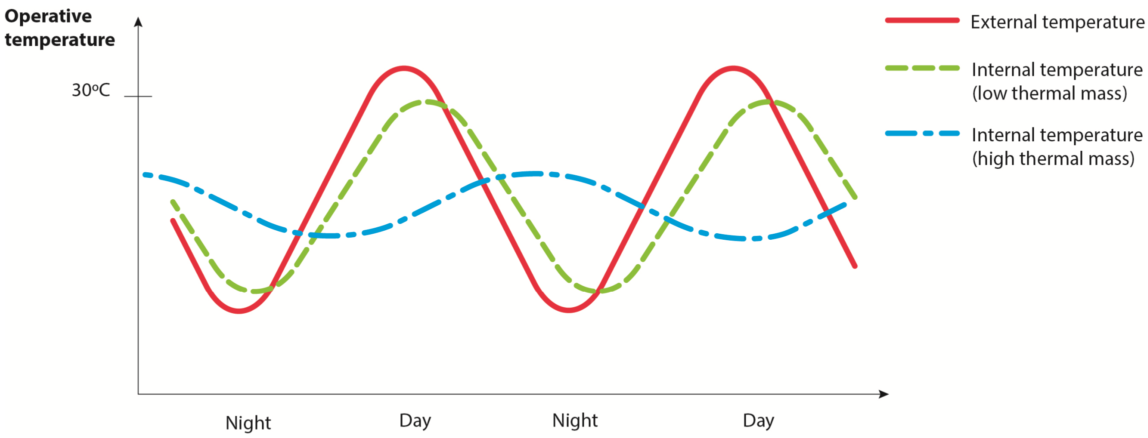


Fig H.26 Indicative operative temperature profiles with/without thermal mass

The thermal mass can be exposed in the space as part of the building fabric (walls, floors or ceilings) to act directly (providing radiant cooling to occupants) or indirectly (such as a thermal labyrinth or air plenum) to temper the supply air. Some considerations for the effective use of thermal mass are as follows:

- The first 75 mm of exposed thermal mass has the most benefit. Buildings therefore don't have to be heavyweight to have thermal mass.
- Will thermal mass provide a clear comfort / energy benefit or would a lightweight approach work better (faster response times)? This depends on both the climate and the functional use of the space – it's not a 'one size fits all' answer.
- The benefit is only realised if the internal air temperature is allowed to rise and there is a means of cooling the mass at night, such as:
  - night purging ventilation (either natural or fan-assisted)
  - pipes cast in the slab and connected to geothermal or night sky cooling systems.
- How night purging may affect building use – the security of ventilation openings at night, occupancy of the building out-of-hours when night purging is occurring and the control system (e.g. how will overcooling be prevented to avoid occupants being too cold in the morning and/or turning the heating on?).

- If fans or pumps are required to activate the thermal mass, does the saving in cooling energy outweigh the fan/pump energy?
- Acoustic issues such as reverberation need to be checked for internal thermal mass. Large expanses of exposed concrete can lead to internal noise problems.

For further guidance on system design, floor types and surface finishes, refer to *Utilisation of thermal mass in non-residential buildings*.[24]

MIMICKING THERMAL MASS

Phase Change Materials (PCM), typically paraffin wax, can be incorporated into lightweight buildings to mimic the effect of thermal mass. The PCMs used in buildings change phase (from solid to liquid) between 22 to 26°C, absorbing energy as they do so. The PCM must then be cooled (e.g. by night purging), releasing the stored energy as it turns back to a solid. PCMs can be incorporated into ceiling or wall panels, partitioning and air supply ducts.

A 5 mm thick PCM panel behaves approximately like 20 to 40 mm of concrete, depending on the temperature, and has 143 Wh/m^2 of heat storage capacity between 18 and 24°C.[25] Computer simulation has shown that a melting point of 26°C is optimal for passive summer heat reduction in buildings, while 23°C is preferred for PCMs incorporated into mechanical air conditioning systems.[26]

H5.4 Reducing heating and cooling of fresh (outside) air

Heating and cooling energy consumption is intertwined with the ventilation strategy. Methods of reducing the energy required to heat and cool the fresh air supply include:

- Reducing the volume of fresh air to be heated / cooled, including demand control ventilation based on CO_2 levels or presence detectors (linked with lighting control system).
- Using heat recovery systems to preheat / precool incoming fresh air supply.
- Avoiding air leakage from ducts (and also ensuring they are well insulated to reduce heat losses).
- Preheating (or precooling) the building prior to occupancy, using 100% recirculated air (i.e. no fresh air component) when this is more energy efficient than heating or cooling volumes of fresh air.
- Providing good ventilation efficiency to ensure that air is well circulated (and avoiding uncomfortable draughts from air grilles or façade openings).

'Free cooling' can be utilised by supplying more fresh (outside) air when external air temperatures are lower than the supply air temperatures, instead of cooling recirculated air.

H5.5 Zoning of systems

The heating and cooling demand can vary across a floor plate due to:

- Solar gains (movement of sun) and/or heat losses in the zone adjacent to the façade.
- Poorly performing facades (draughts and/or cold bridging) creating local discomfort (even if the air temperature is OK).
- Differences in internal heat gains due to level of occupancy and/or office equipment.

Zoning of the heating and cooling systems to suit different requirements can lead to a significant reduction in energy consumption, particularly if the zones can also be switched off when not occupied. Figure H.27 illustrates a simple example of the difference appropriate zoning can make. HVAC zoning is often disrupted during internal fit-outs – a building user and/or fit-out guide is therefore helpful during internal layout changes to explain:

- how the systems work
- how best to zone the systems
- where to position thermostats (out of direct sun and away from high heat sources).

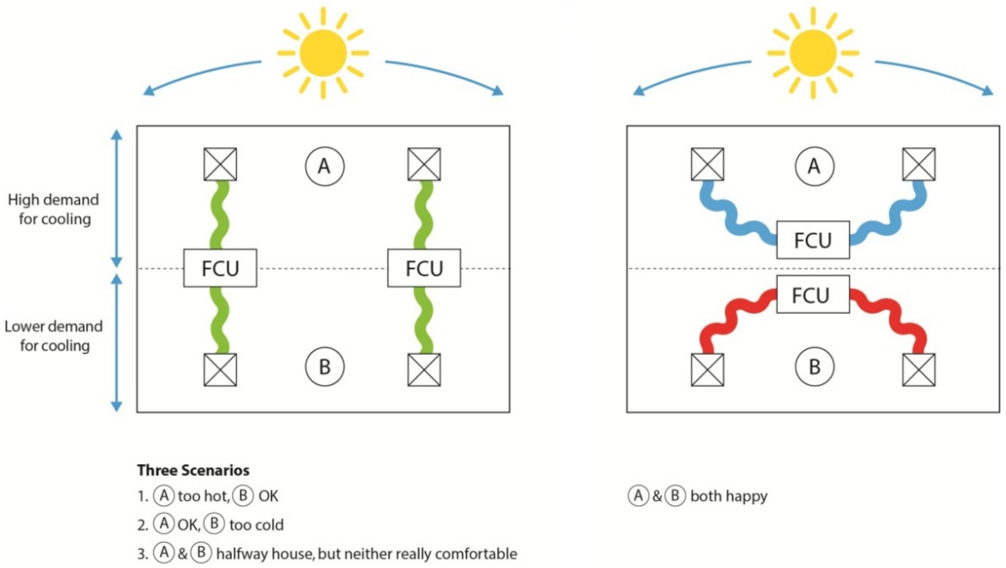


Fig H.27 Simple example of the impact of system zoning

In some HVAC systems, the cooling of the ventilation air occurs only in the central AHU. In these systems, if just one internal zone requires cooling but all other zones require heating (or less cooling) then the air supply to all the other zones must be reheated. To save the cost of heating pipework, electric reheats are often installed in the supply air ducts on each floor. These are inefficient compared to gas boilers or heat pumps and should be avoided where possible. Heater batteries connected to the heating hot water system are preferred if lots of reheating is anticipated. It is better still is to avoid reheating chilled air by providing the cooling in each space locally using fan coil units or chilled beams when viable.

H5.6 HVAC selection criteria

A variety of issues must be considered when selecting a Heating, Ventilation and Air Conditioning (HVAC) system, or components of a system, in a building. Table H.7 shows an example selection matrix that can be used to compare options. The weightings will vary, depending on the priorities of the client.

	Parameter	Weighting	Option 1		Option 2	
			Score	Weighted score	Score	Weighted score
Life cycle costs (to agreed period and discount rate)	Capital cost					
	Energy & carbon costs					
	Maintenance costs					
	Replacement costs					
Sustainability	CO_2 emissions					
	F-gas emissions					
	Rating tool points					
Other	Reliability					
	Resilience					
	Future flexibility - loads					
	Future flexibility - layout					
	Thermal comfort					
	User control					
	Spatial requirements					
	Noise					
	Impact on programme					
	Ease of maintenance					
	Total weighted score	**100**				

Table H.7 Example HVAC evaluation matrix

H5.7 Central plant versus VRF

Table H.8 summarises some of the key components, advantages and disadvantages of conventional central plant (refer to sections H5.8 to H5.11) versus variable refrigerant flow (refer to section H5.13). The table deliberately avoids stating which is the lowest carbon (or life cycle cost) solution as both can be energy efficient, and both can be energy ‘guzzlers’. This depends on many factors, including how well the system is designed, installed, commissioned and maintained.

	Central plant	Variable refrigerant flow (VRF)
Heat generated by	Gas boilers Gas CHP Biomass boilers Solar thermal District heating	Air source heat pump Ground source heat pump
Cooling generated by	Electric chillers Absorption chillers (using heated hot water) Gas chillers Indirect evaporative cooling	
Heat energy distribution	Heating hot water and chilled water in pipes	F-gases (refrigerant) in pipes
Pumps	Various pumps for primary and secondary circuits	Pumps integral to heat pump unit
Controls	Typically a Building Management System (BMS)	Proprietary system typically comes with VRF units. Can be interfaced with BMS.
Metering	Heat meters required to apportion heating and cooling energy to different users. Rarely provided so heating/cooling energy costs usually distributed based on floor area (and sometimes hours of use).	VRF unit can be connected directly to tenant's electricity meter – user pays directly for heating/cooling energy use.
Advantages	Can use a combination of different energy sources providing flexibility for future low carbon technologies. Long life expectancy (>20 years) of many components. Components can be replaced or upgraded separately. Can be extended to serve large number of spaces.	Easy to install. Simple zoning. Often lower capital cost than central plant. Heat recovery systems allow refrigerant to remove heat from one part of the building and transfer it to another space without turning on the compressor. Smaller plant rooms. Gas heat pump can be used when electrical power supply is limited.
Disadvantages	Difficult to sub-meter Can be complex to control and commission Potential for simultaneous heating and cooling - systems fighting each other	Refrigerant pipe runs usually limited to around 10 to 15 storeys. Lots of roof space required for external condenser units. F-gases are potent greenhouse gases (refer to Appendix B). Not easily combined with other energy sources. Often less than 10 year life expectancy.

Table H.8 Comparison of central plant v VRF for heating and cooling

H5.8 Efficient boilers

Most heating hot water (referred to as Low Temperature Hot Water (LTHW) in the UK if below 90°C) in office buildings is generated by natural gas boilers. Alternative sources can be used, including gas CHP and biomass boilers (refer to Chapter 7 for further discussion), although these are typically designed for part or base heating load, with gas boilers also provided to meet the peak demand. If the building is near a district heating system then no boilers are required and the building can be connected directly to this. Oil boilers are sometimes used when there is no access to natural gas.

Steps to reduce the energy consumption of gas boilers include:

- Replacing old boilers (efficiency <75%) with condensing boilers (efficiency >90%).
- Undertaking regular maintenance – this not only improves efficiency but also reduces NOx and SOx emissions.
- Installing weather compensation to reduce heating water temperatures on milder days.
- Isolating stand-by boilers to reduce standing losses.

The demand for domestic hot water in offices is usually quite small – refer to section H8 for options to reduce demand. The use of biomass boilers and solar hot water systems to reduce CO_2e emissions is discussed in Chapter 7.

H5.9 Design of cooling systems

Building services engineers are often conservative as they don't want to be sued for designing a system with inadequate cooling capacity. Consequently, cooling load estimates are often conservative due to one or more of the following:

- Adopting high wet bulb and dry bulb design temperatures, and assuming that these occur at the same time.
- Compounding various safety factors and contingencies.
- Assuming limited load diversity within the buildings.

This can result in the chillers, pumps and fans being oversized. Running equipment at low (part) loads for much of the year usually leads to inefficient operation. If the chiller staging strategy is not worked out properly then this can make matters worse.

The design and management of cooling systems can be complex, but the general principles described in Chapter 6 and this appendix can form a useful starting point when considering their energy efficiency in new and existing buildings.

H5.10 Chillers

Chillers use the refrigeration cycle to generate chilled water. Like heat pumps, chillers can either be air cooled or water cooled. While water cooling via a condenser water loop connected to a cooling tower is more energy efficient, the legionella risk these present if they are not correctly maintained (and the associated cost of maintenance) mean that in many countries air cooled systems are now the most popular choice for office buildings.

Many variables affect the efficiency of chiller systems, including the type of chiller, heat rejection system (and size relative to seasonal loads), condenser temperature, chilled water supply temperature, use of variable speed drives (VSDs) and the age and maintenance history of the equipment.[27]

The most efficient chillers, with potential CoPs greater than 6, typically use centrifugal oil-less compressors with magnetic bearings and variable speed drives. However, the chiller efficiency shouldn't be considered in isolation of any auxiliary systems (pumps, cooling towers, etc.) and the cooling system efficiency is often much less than the laboratory values provided by manufacturers.

Steps to reduce the energy consumption of chillers include:

- Replacing old chillers with modern energy-efficient versions whenever practicable.
- Selecting chillers which provide optimum seasonal efficiency at the typical operating range in the building (which is rarely peak capacity).
- Developing a clear staging strategy so that multiple chillers run at optimum efficiency and avoid chillers running in their least efficient load range.
- Installing VSDs on condenser water pumps.
- Raising the chilled water supply and/or condenser water temperature.
- Regular maintenance.
- Considering if waste heat from the chiller can be used to pre-heat domestic hot water or heating hot water systems.
- Considering if reliable and suitable low carbon heat sources are available for absorption or adsorption chillers to provide base load cooling. Refer to Chapter 7 for more discussion on the marginal benefit of trigeneration (CHP + absorption chiller) in office buildings.
- The Global Warming Potential (GWP) of refrigerants are much more potent than CO_2 and leakage can account for up to 2 $kgCO_2e/m^2$ in an air conditioned building (around 2% of total operating emissions) – refer to Appendix B. Consider low or zero GWP refrigerants and provide methods of detecting and containing any leaks.

Some buildings have primary and secondary chilled water circuits. For example, the primary chilled water circuit may supply water at 6°C to the air handling unit for dehumification, while the secondary circuit may supply active chilled beams at 14 to 15°C. The secondary circuit is typically fed from the primary circuit, either by mixing valves, or using a heat exchanger. Chilling water more than necessary wastes energy. Methods to reduce energy consumption include:

- Considering if refrigerated cooling is required – can evaporative or ground source cooling be used instead?
- Adjusting chilled water temperature set points when conditions permit – e.g. if no dehumidification is required or there is limited cooling demand, does the water need to be chilled to 6°C?
- Considering if free cooling can be used. This allows the chilled water to bypass the compressor when the outside temperature is low enough, with the condenser water alone satisfying the cooling demand.

- Considering two separate chillers – one for dehumidification (6°C) and one for chilled beams (15°C). This may create issues with redundancy if one chiller fails, unless they are piped together.
- Utilising chilled water storage in large developments. A large insulated tank of water is cooled down at night (when the chillers operate more efficiently and the electricity tariffs are much lower) and the water is drawn off during the peak cooling period the next day.

As with any system, regular maintenance of chillers should be undertaken, including mandatory air conditioning and F-gas inspections required under EU legislation.

H5.11 Pumps and pipework

Pumping energy can account for 10 to 20% of the total heating and cooling energy consumption. Opportunities to reduce energy include:

- Using efficient motors with variable speed drives (VSD) on larger pumps – refer to section H4.9 on fans for details.
- Using direct drive motors in preference to belt-driven motors.
- Considering providing two pumps (each sized at 60% capacity) to provide redundancy and so that only one pump needs to operate at low loads. Pumps are inefficient at low loads so if two are used, they can operate more efficiently at part loads than using a single pump sized at 100% with an equally sized stand-by pump sitting alongside.
- Avoiding unintended small loads on the primary chilled water circuit.
- Reducing the resistance of the distribution circuit by avoiding undersized pipes and limit the number of sharp bends.
- Pipework should be well insulated, including valves, to reduce heat losses.

H5.12 Humidity control

In most buildings the ideal humidity level is 40 to 60%, although 30 to 70% can usually be tolerated without too many issues. If the air becomes too dry then this can lead to problems with dry throats / eyes and static electricity. If the air is too humid then this can cause discomfort and condensation (particularly on the surface of chilled beams), or in extreme cases mould growth inside the buildings (walls, ducts, ceilings, etc.), especially where there is insufficient ventilation.

Humidification of the air is provided by the injection of steam into the supply air. This is very energy intensive and is not really necessary in most office buildings due to the UK climate. Dehumidification is usually provided by the reduction of the supply air temperature until the dew point is reached, and occurs as part of the cooling process. The water condenses on the cooling coil and the condensate drains away. The air is then reheated to the desired temperature by the heating coil. This is also an energy-intensive process. More energy-efficient alternatives include using an enthalpy wheel, but these require additional equipment (and space) and so are rarely used in office buildings.

The most energy-efficient approach to humidity control is to avoid it whenever possible.

COOLING OF SERVER ROOMS

Servers run for 8,760 hours per year so finding a solution which reduces the associated server cooling energy consumption is a key component of a tenant's fit out design:

- Provide realistic cooling loads (do not use the equipment nameplate loads) to the mechanical engineers to avoid oversizing cooling equipment, operation at inefficient part loads and overcooling of the rooms – refer to section H7.6.
- Ensure that server racks have good air circulation through them to remove the heat efficiently – refer to Figure H.28.
- Explore which air temperature is required to avoid servers failing (tripping out). Most servers will still work perfectly well at air inlet temperatures higher than 24°C.
- For small rooms, consider an exhaust fan linked to a thermostat. This turns on an exhaust air fan when 24°C is exceeded, drawing air through an outside air grille (with dust filter) or via a door grille from an internal space. An air conditioning unit can be utilised with this system which turns on only when the exhaust fan cannot maintain temperatures below, say, 28°C.
- Can the computer / server room be naturally ventilated to reduce air conditioning requirements (potentially combined with thermal mass or phase change materials)? Humidity control and air filtration requirements may preclude this.
- Avoid connecting the server room cooling to the building cooling system unless it has been designed specifically for this.[28]

Figure H.28 shows a couple of potential cooling options for server rooms.

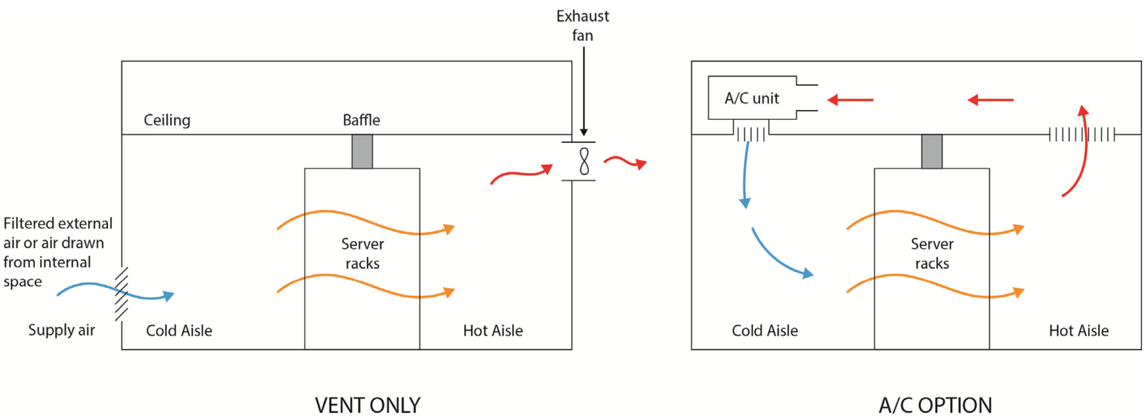


Fig H.28 Options for efficient cooling of office server rooms

H5.13 Variable refrigerant flow (VRF) systems

VRF systems can operate more efficiently at part load than large chillers due to the multiple number of compressors (effectively miniature chillers) making up the system. Indoor units can be controlled individually or grouped together, giving occupants direct control of cooling/heating, and sometimes the ability to adjust set points (although this facility is often locked by the building facility manager and controlled centrally).

To improve the energy efficiency of a VRF system, the following guidelines can be considered:

- Air cooled external units should be located in spaces with good air flow to allow efficient rejection of heat. Poor air flows can increase energy consumption of the VRF system by up to 30%.
- VRF systems using ground/water source heat pumps are more efficient than air source but the area of land required and capital cost for such systems (pipes in trenches, boreholes, energy piles, aquifer thermal storage, etc.) may make these unfeasible. Refer to Chapter 7 for further discussion on heat pumps.
- Keep refrigerant pipe lengths to a minimum as pressure losses reduce the heating/cooling capacity of indoor units. For longer pipe runs (say over 50 m), increase the pipe diameter to reduce pressure losses.
- For buildings requiring simultaneous heating and cooling, heat recovery VRF systems can be used. These systems sometimes use three pipes instead of two to circulate refrigerant between zones, transferring heat from units providing cooling to those providing heating (refer to Figure I.16 in Appendix I).
- Interlink the VRF system with any other heating systems so that the systems don't fight each other.

H5.14 Further guidance on heating and cooling system design and operation

- *Heating, ventilating, air conditioning and refrigeration*, CIBSE Guide B, 2005.
- *Energy efficiency in buildings*, CIBSE Guide F, 2012.
- *How to design a heating system*, CIBSE Knowledge Series KS8, 2006.
- *The Illustrated Guide to Mechanical Cooling*, AG 15/2002, BSRIA.
- *The Illustrated Guide to Mechanical Building Services*, AG 15/2002, BSRIA.
- *A Guide to Building Services HVAC Calculations*, BG 30/2007, BSRIA.
- *HVAC Systems and Equipment*, ASHRAE Handbook 2008.
- *HVAC Applications*, ASHRAE Handbook 2011.
- *Fundamentals*, ASHRAE Handbook 2009.

H6. LIGHTING

H6.1 Lighting energy – EPC v ECON 19

In an operational air conditioned office building in the UK, the typical existing lighting benchmark from ECON19 (refer to Appendix C) is 54 kWh/m^2, based on a total power density of 20 W/m^2. This represents 24% of the total carbon footprint of 135 kgCO_2e/m^2 (excluding small power). The ECON 19 lighting benchmark for good practice is based on 12 W/m^2 is 27 kWh/m^2 which represents 24% of the total carbon footprint in a good practice office of 68 kgCO_2e/m^2 (excluding small power). New lighting systems are typically less than 10 W/m^2 so the proportion of lighting energy consumption in the operating carbon footprint of a typical office building is likely to be lower.

In the Part L Building Regulations 2010 and Energy Performance Certificate (EPC) energy modelling calculations which exclude small power, lighting typically represents 35% of the total. While this leads to a focus on lighting energy efficiency (which is a good thing), it does mean that a disproportionate weighting is given to lighting efficiency and controls (e.g. motion sensors and daylight dimming) to get a good EPC rating, at the expense of improving other systems in the building.

H6.2 Types of lamp

Table H.9 shows the typical types of lamps, their efficacy and expected lamp life.[29]

Type	How it produces light	Common examples	Typical lamp efficacy (Lm/W)	Average lamp life (hours)
Incandescent	Glowing filament	Standard light bulb Tungsten Halogen (12v / 240v) *	10 – 13 15 – 22	1,000 2,000 – 5,000
Fluorescent	Glowing gas	Tubular ** Compact	60 – 100 50 – 85	8,000 – 80,000 8,000 – 24,000
Solid state	Photons from semiconductor	Light emitting diode (LED)	1 – 100	10,000 – 100,000
Discharge	Glowing gas	Metal halide High pressure mercury *** High pressure sodium *** Low pressure sodium ***	75 – 90 40 – 55 50 – 130 100 – 200	8,000 – 15,000 9,000 – 24,000 8,000 – 24,000 10,000 – 16,000

* transformer required for 12v version
** electronic ballast required
*** typically used in external applications due to poor colour rendering and extended time to reach full brightness

Table H.9 Types of lamp

A key challenge with LEDs in the past has been the lack of standard fittings – replacing a faulty lamp often required the replacement of the whole fitting. In April 2012, the major lighting manufacturers agreed a series of standards (known as ZHAGA Books 1 – 7) which should result in standard LED fittings, making lamps by different manufacturers interchangeable.

H6.3 Luminaires

Table H.10 shows the typical types of luminaires used in office buildings. These are available for fluorescent and LED lamps.

Type	Description	
Louver	Original 'egg crate' design to reduce glare. Rarely used in new buildings or refurbishments.	
Recessed coffer	Indirect lighting can also have direct component (louvres or prismatic in centre) as shown.	
Suspended	Provide indirect (upward) and direct (downward) light. Left – louvre Right - prismatic	
Micro-prismatic diffuser	Prisms formed in polycarbonate with varying angles on sheet to evenly distribute light.	
Down light	LED fittings now commonplace.	

Table H.10 Types of luminaire typically used in offices (images courtesy of Zumptobel)

H7. EQUIPMENT

H7.1 Stand-by power

The International Energy Agency established the One Watt initiative in 1999 which set stand-by energy targets of 1 W by 2010 and 0.5 W by 2013.[30] EU regulation 1275, introduced in 2008, adopted these requirements for standby and 'off' mode electric power consumption of electrical and electronic household and office equipment. An exception was made for equipment providing information or status display, which has limits of 2 W initially, which will be reduced to 1 W by 2013.

H7.2 Small power energy consumption estimate

Figures 6.15 and 6.16 in Chapter 6 were based on the assumptions shown in Table H.11 and the calculations shown in Table H.12. A similar approach can be used to estimate equipment energy consumption in any office to identify the key targets for reduction.

Item	Value	
Working hours	50	per week
Size of office	1000	m^2 of NLA
Occupant density	10	m^2 per person
No. of people	100	
Office closed - holidays, etc.	4	Weeks per annum
Working weeks	48	Weeks per annum
Photocopier	33	people per unit
Fridge	33	people per unit
Kettle	1	mins per person per day
Microwave	1	hour per day
Server	30	W per person
	3000	Watts when ON
	20%	Turn down in capacity in stand-by
	2400	Watts in "stand-by" – i.e. not full capacity
	3	COP of server room cooling system

Table H.11 Assumptions for small power energy consumption estimate

	No. of	ON (Watts)	Stand-by / Idle / Off (Watts)	Diversity	Hours ON during working hours	Hours ON during non-working hours	kWh/m² of NLA per annum		
							Working hours only	Non-working Hours	Total Hours
Server	1	3000	2400	100%	50	0	7	15	22.4
A/C unit for server cooling	1	1000	800	100%	50	0	2	5	7.5
Computers	100	70	5	70%	50	0	12	3	14.9
Monitors	100	30	2	70%	50	0	5	1	6.3
2nd Monitors (50% of people)	50	30	2	70%	50	0	3	1	3.2
Photocopiers	3	200	5	100%	50	0	1	0	1.5
Fax machine	1	20	15	100%	50	0	0	0	0.1
Fridge	3	150	100	100%	50	0	1	2	3.0
Microwave	2	50	5	100%	5	0	0	0	0.1
Kettle / boiling water unit	1	2000	5	100%	8	0	1	0	0.8
Phone chargers	1	1	1	50%	50	0	0	0	0.01
TV in reception	1	100	5	100%	50	0	0	0	0.30
TOTAL							**33**	**28**	**60**

Table H.12 Calculations for small power energy consumption estimate

H7.3 Improvements in electrical equipment efficiency versus consumption

The improvement in the energy efficiency of fridges in the United States since the mid-1970s provides an illustration of what is possible with targeted legislation. Between 1947 and 1976, the energy consumption of fridges increased by more than 400%. Due to market forces, there was no incentive for energy efficiency.

After the first efficiency standards were introduced in 1976, the least efficient half of the market was eliminated. Over the next 30 years, a regular series of increasingly stringent standards (accompanied by other incentives) led to more innovative products with more features, at lower costs (a 60% reduction between 1976 and 2010) and a 70% reduction in energy consumption.[31]

The EU and Australia both have energy efficiency rating schemes for fridges. The rating scale in Australia has been recalibrated twice since it was introduced in 1986 to reflect the improving efficiency of fridges. As all the fridges approached 5 stars, the scale was reset so that this performance became average and to differentiate products in the market place the new 5 stars became the target to reach.

In the EU, the scale originally went from 'A' to 'G'. Legislation setting minimum efficiency standards meant that the 'E' to 'G' ratings became redundant, but instead of recalibrating the scheme, the scale was changed to 'A+++' to 'D'. History suggests that within 10 years the scale will go from 'A' to 'A+++++++' unless common sense is applied and a revised 'A' to 'G' scale reintroduced.

However, energy efficiency alone doesn't mean lower energy consumption. As fridges get bigger, the surface area to volume ratio decreases, which means that there is less heat loss through the casing. Consequently, their energy efficiency (cooling energy per m^3) improves, but they still consume more energy than smaller fridges (which appear less efficient) because they have a larger volume to cool.

H7.4 Power management strategy energy consumption estimate

Figure 6.17 in Chapter 6 was based on the assumptions in Table H.13.

	On	Stand-by	Off	Total
Computer (W)	70	5	0	
Monitor (W)	30	2	0	
Total	**100**	**7**	**0**	
Good power management				
Hours on	50	118	0	168
Time off during day	20%			
Total hours	40	128	0	168
Energy consumption (Wh/week)	4	0.9	0.0	4.9
Energy per annum (kWh)	**192**	**43**	**0**	**235**
Poor power management				
Hours on	120	48	0	168
Time off during day	0%			
Total hours	120	48	0	
Energy consumption (Wh/week)	12	0.3		
Energy per annum (kWh)	**576**	**16**	**0**	**592**
Turn off at mains				
Hours on	50		118	168
Time off during day	20%			
Total hours	40	10	118	168
Energy consumption (Wh/week)	4	0.07	0	
Energy per annum (kWh)	**192**	**3**	**0**	**195**

Table H.13 Assumptions and calculations for power management strategy energy consumption estimate

H7.5 The impact of server rooms on energy consumption

To put server room energy consumption into perspective, consider Building X: a 10,000 m^2 office building with annual operating carbon of 105 $kgCO_2e/m^2$ of GIA – refer to Appendix M for details. A tenant decides to install a 200 m^2 server room with 40 racks of virtual servers to provide IT functionality both within the building and for external operations (e.g. smaller regional offices).

A typical server rack might have a peak electrical load of 5 kW, so 40 racks has a total load of 200 kW (equivalent to 1,000 W/m^2 in the server room). Assuming a further 100 kW of electricity is required for supporting equipment such as cooling, lighting and so on, this gives a total peak electrical demand of 300 kW (1,500 W/m^2).

The efficiency of large data centres is often measured using the Power Usage Effectiveness (PUE), which is determined by dividing the amount of power entering a data centre by the power used to run the computer infrastructure within it. For the server room in Building X, the PUE is 300 / 200 = 1.5. The most efficient data centres in 2012 have a PUE of around 1.2 with industry averages of between 1.5 and 2.0,[32] so the performance of Building X's server room represents good practice in the IT industry.

Assuming the average annual load is 70% of the peak load (virtual servers don't run at full capacity all the time) then the annual energy consumption of the server room would be = 300 kW x 24 hours x 365 days x 70% = 1,840 MWh (or 184 kWh/m^2 of whole building GIA). This is more than the total electricity consumption of the lighting, small power, ventilation and cooling in the building (150 kWh/m^2) and adds 110 $kgCO_2e/m^2$, more than doubling Building X's operating carbon footprint, all from a room occupying just 2% of the floor area.

It is essential that server rooms are sub-metered in office buildings, particularly if the energy consumption of the room is allowed to be excluded from a formal energy rating. Reducing the energy consumption of IT servers in buildings is clearly far more important than unplugging a few phone chargers.

CASE STUDY: REDUCING SERVER ENERGY BY 80%

In 2011 Cundall designed a virtualisation server strategy in a campus college. Before this, the college had 30 servers each consuming 500 W for 8,760 hours per year giving an annual equipment energy consumption of 131,400 kWh. On top of this there was another 50% for cooling energy (65,700 kWh).

The system was replaced with three new 1 kW virtualisation servers. During peak periods, all three are on, but outside peak hours only one server is required. The electricity consumption with one server on 8,760 hours is 8,760 kWh, and with two servers on 2,000 hours is 4,000 kWh. The total energy consumption reduced to 12,760 kWh, one tenth of that of the existing system.

This approach was possible because virtual server software can be configured to allow the number of servers online to be adjusted to suit the work load demands. It is automatic, so as staff and students log on in the morning, additional servers come online to take up the load. It is more or less instant, so in effect all of the peak processing power is available when required at any time.

On this project, dual servers and data storage were installed on two separate sites for resilience (and to avoid needing to take back up tapes off site) so the net energy reduction was only 80% - but the college gets a much faster system with automatic data back-up and storage on two sites 5 km apart.

H7.6 Avoiding overdesign of cooling in server rooms

The capacity of cooling systems in server rooms is often overdesigned because of the difference between 'name plate' load (in Watts) and the actual power demand of IT equipment. IT equipment vendors construct their equipment using a selection of suppliers who all put a margin on the peak load of their components. These are all added together and then a margin is put on top, so equipment with a stated load of 1 kW might actually only draw 0.6 kW or produce 0.6 kW of heat.

The cooling design engineers take the 1 kW figure and then may add a safety margin onto that as well. As discussed earlier, running a system at part load is often inefficient, and providing more cooling capacity than is required wastes money. Oversized plant can sometimes cause problems maintaining stable operational conditions.

It is difficult for designers to challenge the original figure of 1 kW because the equipment manufacturers or IT suppliers are often unwilling to agree to a lower figure. For example, on a Cundall project in 2012, existing IT equipment was being moved from one facility to another location. The actual metered demand of the equipment in the existing facility was significantly lower than the load calculated by adding up all of the 'name plate' loads stated on the equipment. The client's ICT consultants insisted on designing the new location for the base plate load which led to an oversized cooling system always operating at inefficient part loads.

H7.7 Outsourcing IT functions to data centres

Outsourcing IT functions, such as processing and data storage, to large data centres is now common practice. This reduces the energy consumption in office buildings, but simply transfers the problem elsewhere. There is very little transparency about the energy consumption of individual large data centres.

In 2007 data centres accounted for 1.5% of Australia's total energy consumption, and it is estimated that internet usage will grow by 36% per year between 2011 and 2016 due to a combination of new users connecting, users demanding more and higher quality data and an increase in mobile activity.[33] A study by the New York Times in 2012 found that 2% of electricity in the United States was used in data centres.[34] Other findings from the study included the following:

- On average, data centres use only 6 to 12% of the electricity powering their servers to perform computations.
- Online companies typically run their facilities at maximum availability around the clock, whatever the demand. As a result, data centres can waste 90% or more of the electricity they take from the grid.
- Worldwide, data centres use about 30 billion Watts of electricity.
- The number of US federal data centres grew from 432 in 1998 to 2,094 in 2010.
- In 2012 there were more than three million data centres of widely varying sizes worldwide, according to figures from the International Data Corporation.

Typically non-virtualised servers use less than 10% of their processing capacity on average, while highly virtualised servers use less than 30% of their processing capacity on average. However, they may still draw their full electrical power, even when delivering a fraction of their capacity, and remain on 24/7 to be ready to meet peak demand at any moment. While software exists to power down servers when they are not needed, and to place large applications in a queue so that they can be scheduled to run in low use periods (allowing servers to run above 90% efficiency 24 hours a day), the IT industry is nervous about not being able to hit peak demand at any moment in time. Consequently, huge amounts of redundancy are built into the systems, which wastes huge amounts of energy.

Historically, energy efficiency in data centres has been very much focused on the mechanical and electrical infrastructure and benchmarked using the Power Usage Effectiveness (PUE). However, this is increasingly coming under scrutiny as there are so many ways in which it gets presented (partial, annual, partial for system, or partial for individual hall), because it can be distorted (operators may choose to portray the UPS losses as a loss, or as part of the IT load), and because it does not pick up on how much actual data processing is going on. It is becoming increasingly apparent to some operators that a low PUE does not automatically translate into an energy efficient site if the IT equipment is not actually doing much useful processing work for the power it consumes. Operators are starting to ask their server suppliers to declare what the standby power consumption of their equipment is compared to fully loaded peak power, as this gives a much more realistic picture.

The first national tool to benchmark the energy consumption against productive output, the *NABERS Energy for Data Centres* rating tool, was released in Australia in January 2013. It provides three different ratings, depending on who controls the energy (similar to the tenant, landlord and whole building ratings in offices):

- **IT equipment rating** – is for organisations who own or manage their IT equipment (including servers, storage devices, network equipment) and who have no control over the data centre support services such as air conditioning, lighting and security. It is based on comparing energy consumption with the productive output, a combination of processing capacity (in GHz) and data storage provided (TB).
- **Infrastructure rating** – is for data centre owners and managers. It uses the Power Usage Effectiveness (PUE) ratio to determine the facility's energy efficiency in supplying the infrastructure services to the IT equipment (owned and controlled by others) housed in the data centre.
- **Whole facility rating** – this combines the IT equipment and infrastructure ratings and is designed for organisations that both manage and occupy their data centre, or where internal metering arrangements do not permit a separate IT equipment or infrastructure rating.

Other benchmarking tools are being developed, but at the start of 2013 there was no internationally agreed standard metric to benchmark the energy efficiency and carbon performance of data centres.[35] Adopting the approach taken by NABERS would be a good start.

When processing and storage capacity in offices is outsourced to data centres, it may make the building look more energy efficient, but the problem has just been moved elsewhere. The 'cloud' isn't light and fluffy – it's a lot of very large, anonymous energy-intensive sheds filled with tons of electrical gear. To reduce the energy consumption associated with outsourcing IT function from offices, organisations should consider reducing the amount of unnecessary data that is stored on the servers (which also saves a lot of money). Also, ask if the IT provider will provide any of the following:

- The PUE of the data centre.
- The NABERS Energy rating (or equivalent) for their facility.
- A statement of the annual energy consumption associated with the IT functions that they provide so that this can be added to your company's annual carbon footprint.

H7.8 The hidden energy of phones

Many devices are powered using a Power-over-Ethernet (PoE) switch. Typically, these deliver 15 W per port but more recent standard PoE-plus allows of up to 30 W per port. Many modern offices now have a phone system connected to the ICT system which consumes energy 24/7.

To put this energy consumption into perspective, consider Building X, which has 665 occupants in 10,000 m^2 of GIA. Allowing for meeting room phones and wi-fi access points, the total number of phones and wi-fi points is 750. There are sixteen 48 port PoE switches (consuming 200 W each) supporting phones and Wi-Fi access points which consume 2.5 W each. The total electricity consumption is 44,425 kWh (2.7 $kgCO_2e/m^2$ of GIA), which is around 2.5% of the total annual energy consumption:

- 16 x 200 W = 3.2 kW x 8,760 = 28,000 kWh
- 750 x 2.5 W = 1.9 kW x 8,760 = 16,425 kWh

New systems are available which allow phones and wi-fi points to be switched off out-of-hours. If 90% of the phones and wi-fi points were switched off between 7pm and 7am during weekdays and over the weekend then the annual amount of hours is reduced from 8,760 to 3,120. The total energy consumption is reduced by 20% to 34,905 kWh (2.1 $kgCO_2e/m^2$ of GIA):

- 16 x 200 W = 3.2 kW x 8,760 = 28,000 kWh
- 75 x 2.5 W = 0.19 kW x 8,760 = 1,640 kWh
- 675 x 2.5 W = 1.7 kW x 3,120 = 5,265 kWh

This is another example of how simply switching equipment off when it is not needed is the simplest and most cost-effective way of saving energy in buildings.

H8. OTHER BUILDING SERVICES

H8.1 Domestic hot water

If the taps or showers installed in an office building are not water efficient then the following water saving measures can be considered to reduce hot water consumption:

In-line flow restrictor
Fitted in-between the flexible hose and the tap fitting, or between the wall fitting and the shower arm. Reduces water flow to between 4 and 10 litres/min depending on type selected.

Tap flow limiters
Fitted inside the inlet pipe of the tap, then the pipe is connected to the tap in the usual way.

Isolating valve
Typically fitted to the pipe connection to all new taps. Simply turning the valve slightly to reduce flow will reduce hot water consumption.

H8.2 Lifts

In a study in 2010, it was estimated that there are about 4.8 million lifts installed in the European Union and that energy savings of more than 65% are possible using the best technologies available.[36] The study recommended that:

- A European standard for measuring the energy consumption and calculation of energy demand of lifts and escalators should be developed to enable comparisons between different systems and designs.
- Lifts and escalators should be included within the Energy Performance of Buildings Directive (EPBD) to improve energy efficiency.
- Easily accessible and understandable information for buyers of lifts and escalators should be developed to support decision-making processes.

FURTHER GUIDANCE

- *Transportation systems in buildings*, CIBSE Guide D.
- *E4: Energy Efficient Elevators and Escalators*, a report by ISR University of Coimbra (Portugal) for Intelligent Energy Europe, March 2010.

H8.3 Car park lighting and ventilation

Ventilation

The natural ventilation of car parks in the UK typically requires openings to fresh air being provided with:

- an open area not less than a minimum percentage of the floor area of the car park:
  - 5% for ventilation of everyday vehicle pollution and smoke (the openings provided must be sufficient to create a through draught)
  - 2.5% for smoke clearance only
- at least 50% being provided in opposite faces of the building.

If only 2.5% is provided, a supplementary carbon monoxide (CO) ventilation system is required to limit the concentration of CO (from car exhaust fumes) within the space. In underground car parks where natural ventilation is not possible, mechanical supply and/or exhaust systems are required to limit the concentration of CO within the car park to below 30 parts per million, averaged over an eight-hour period, and must be capable of extracting smoke at 10 air changes per hour.

Mechanical systems have traditionally used long lines of sheet metal ducts with grilles at regular centres. Jet or induction fans, which were originally developed for ventilating tunnels, are now widely used in new car parks and do not require ducting. They propel a small jet of air at a high velocity near the ceiling soffit, causing the surrounding air to be entrained, and moving larger volumes of air towards the main exhaust fans.

To optimise the design of natural and mechanical systems, Computational Fluid Dynamics (CFD) modelling can be undertaken to determine air flows and to identify dead areas where fumes might build up.

Lighting

Car parks require different lighting levels depending on the activity that takes place. For example, in higher risk zones such as ramps, entrance, exits, corners and central circulating lanes then a minimum of 150 lux should be provided. The lighting above the parking bays can be reduced to 75 lux.

A good design, using efficient lamps and luminaires and appropriate positioning should achieve a lighting power density of under 2.5 W/m^2.

H8.4 Other systems

There are many other systems consuming energy in buildings. While they may be relatively small, the consumption all adds up, particularly if they are on 24/7, such as security systems.

Sometimes the energy use can come from unexpected sources. On a PassivHaus school project, the design team couldn’t understand why the metered electricity consumption was much higher than expected. This was eventually traced back to an electric heating element in an external fire sprinkler tank installed to prevent freezing.

H9. COMMISSIONING, HANDOVER AND MAINTENANCE

H9.1 Commissioning process

The BSRIA Model Commissioning Plan[37] provides a template for documenting the scope, responsibilities, processes, schedules and documentation for eight stages of the commissioning process. These are summarised in Table H.14.

	Stage	Actions
Commissioning management plan	1. Preparation	The commissioning team should be formed to develop the process and strategy.
	2. Design	Commissioning team to review design to ensure commissionability and maintainability.
	3. Pre-construction	Ensure that all commissioning information is carried through to the construction phase and given to the contractor.
	4. Construction	Ensure that the engineering systems are physically complete and correct, including static testing.
Initial (static) commissioning to satisfy the specification	5. Commissioning of engineering services	Carry out functional performance tests to verify performance before sign-off and handover.
	6. Pre-handover	Training and familiarisation of the building occupants and managers to ensure that the operation of the building is understood.
Continuous commissioning, incorporating seasonal commissioning and system fine-tuning	7. Initial occupation	Apply feedback from the building's initial performance and experience of occupants to fine tune and debug systems.
	8. Post-occupancy aftercare	Fine tune the building to reflect changes in energy load and patterns of use.

Table H.14 Model commissioning plan outline (source: BSRIA BG8/2009)

FURTHER GUIDANCE

- *Model Commissioning Plan*, BSRIA Guide BG8/2009
- CIBSE Commissioning Codes
- BSRIA Commissioning Guides
- *Seasonal Commissioning*, BSRIA Guide BG44/2013
- *The Commissioning Process*, ASHRAE Guideline 0-2005
- *LEED Commissioning Authority requirements,* LEED 2009 Reference Manual

H9.2 Soft landings and handover

The Soft Landings Framework delivers greater involvement of designers and constructors with building users and operators before, during and after building handover. The key components are:

- constructive dialogue from the early stages of the project
- regular pit stops to reality check designs
- a well thought-through handover process
- extensive after-care service of three years.

Figure H.29 shows how soft landings could be incorporated into the programme for a project.

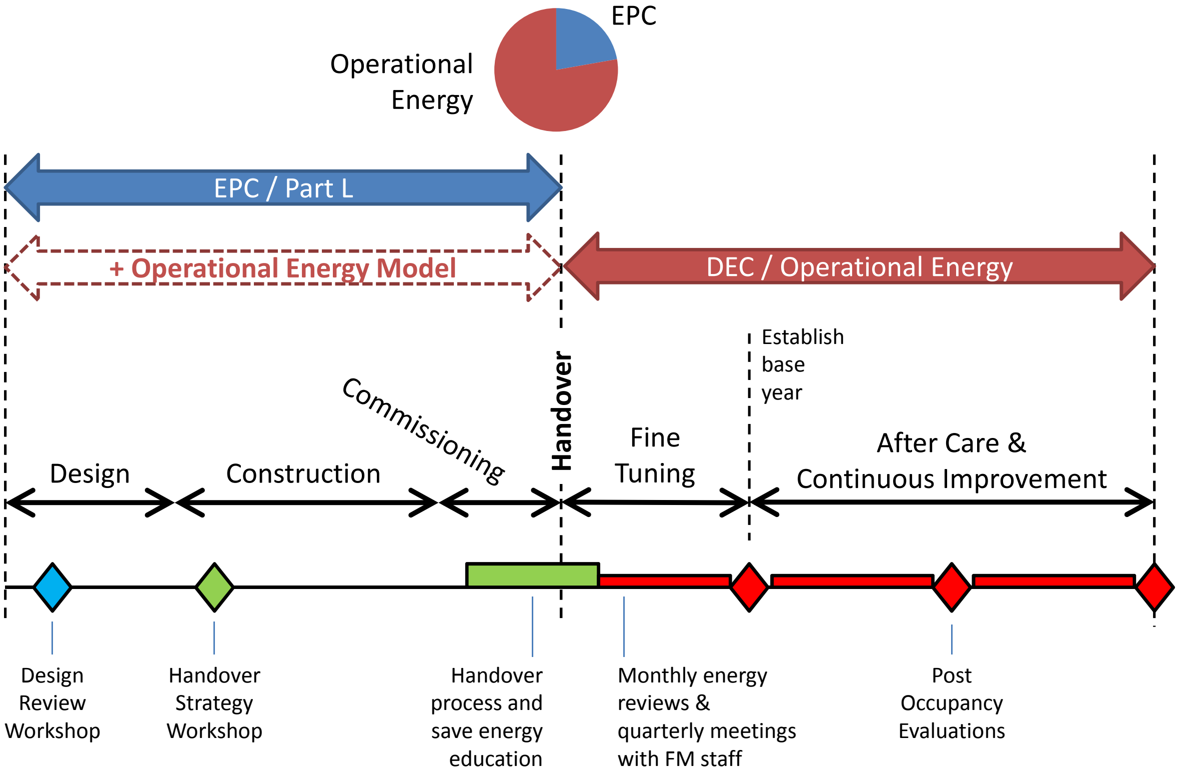


Fig H.29 Example soft landings framework activities in project delivery

This can only result in better performing buildings and lower energy consumption, and is undoubtedly a great initiative that few in the building industry would argue against. The main challenge is that of cost – who pays for it, particularly in the commercial office sector when the developer of the building may not be the long-term building owner?

For the building industry, it is clearly additional work, compared to a traditional approach. From a client's point of view, why should they pay more to get a building which actually performs to the standards promised by the designers and builders? This will require some compromise on both sides and a recognition that the 'build 'em fast and cheap' approach has not necessarily delivered buildings in operation. Ultimately, to make soft landings happen, it needs to be clearly written into the designers' and contractors' procurement contracts. The typical cost is estimated to be around 0.5 to 1% of additional fees.

Further guidance on how to set up contracts to include soft landings, without heavy legal definition which can compromise the spirit of collaboration and shared risk at the heart of the process, can be found in the BSRIA publication *How to Procure Soft Landings – specifications and supporting guidance for clients, consultants and main contractors* BG45/2013.

H9.4 Post-occupancy evaluation (POE)

Post-occupancy evaluation is a structured review of a building's performance, including occupant satisfaction and energy consumption. Various guidelines on how to undertake POEs can be found on line. The *Building Use Studies Occupant Survey Method* developed by the Usable Building Trust is a reasonably cost-effective approach.[38]

Probably the most comprehensive publicly available POEs undertaken in the UK are from the *Post-Occupancy Review of Buildings and their Engineering* (PROBE) research project which took place between 1995 and 2002. The aim was to 'provide feedback on generic and specific information on factors for success in the design, construction, operation and use of buildings, together with areas of difficulty and disappointment.' Many of the reports can be downloaded from www.usablebuildings.co.uk.

FURTHER GUIDANCE

- *Guide to Post-Occupancy Evaluation*, British Council for Offices, 2007.
- BRE Design Quality Method.

H9.2 The challenge of getting complex control systems to talk to each other

Control systems in buildings are becoming increasingly complex, and many different systems are now expected to talk to each other. For example, a meeting room might have a booking software system which talks to the security system and also turns on the lights and HVAC system prior to the meeting and then off afterwards. While a couple of simple switches (with a manual on / manual off / absence off control) would also do the job, they are just not as 'sexy'.

If a complex-integrated system is proposed then it is essential that system design is translated into installation via a process that ensures all personnel involved in the procurement, installation and commissioning process are fully aware of the final operational requirements.

The guidelines in Table H.15 can be considered in addition to normal commissioning requirements.

	Description
1	The design engineers must fully appreciate the implications of system integration rather than assume that because specific systems are specified (such as BMS, lighting control, solar blind system, security, fire alarms, etc.) that the integration will automatically occur.
2	The requirements for system integration should be clearly identified during the detailed design process. In particular, the interface points and requirements must be clearly defined. It is not sufficient to provide a description and expect the sub-contractors to sort out the details because invariably this will lead to problems on site.
3	Where systems fall in to different packages (e.g. BMS, mechanical, lighting control, security, AV, room booking software, etc.), it is essential that workshops are held by the commissioning manager before the procurement process to ensure that each supplier and installer fully understands what the design requires and how the necessary interfaces will work.
4	Technical submittals cover the specified systems but invariably fall short of integration with other systems, usually only referring to the differing communication interface protocols that are available. For example, this can end up with plant having a Modbus interface trying to communicate with a Lon-works controller. The Commissioning Manager should develop a robust strategy during design, procurement and commissioning stages to ensure that responsibility for communication between systems is not left in 'no man's land.' Someone has to take responsibility.
5	Commissioning engineers, whilst being fully conversant with their own particular equipment, don't always fully appreciate what the interfaces are with other systems and the processes involved in 'cross communication' between packages. The Contractor's commissioning process (and associated documentation) should clearly address this.
6	Descriptions of operation for systems must be transferred to the installation team. Any decisions made at site level which modify the operation of the systems must be referred to the design team. The Commissioning Manager should develop a procedure to deal with changes made to systems during installation.
7	It is sometimes preferable that the interface between systems uses hardware rather than software. While most systems can link together over a common IT network, they all speak different languages (or use different words in the same language), and bespoke software is often required to translate outputs between systems. It is therefore important that an open protocol approach is adopted wherever possible. When a system is upgraded in the future the bespoke interface translation software will also usually need to be upgraded (this is often forgotten) so that the two systems can still talk to and understand each other. A physical connection between systems, with electronic signal outputs at the interface, can avoid this problem.
8	The Contractor must develop detailed plans on how each system will communicate with interconnected systems, and include this in the O&M manuals so that any future changes to systems can be made without compromising the integration of the controls systems and the satisfactory operation of the facility.

Table H.15 Guidelines for commissioning complex integrated control systems

H9.5 Maintenance and management

Facility managers and maintenance contractors often have the enviable task of making buildings work, long after the defects liability period has ended and the designers and contractors have disappeared. The topic of maintenance and management is, however, much too big to cover here.

FURTHER GUIDANCE

- *Heating, ventilation and air conditioning: Saving energy without compromising comfort*, CTV046, Carbon Trust, 2011.
- *Maintenance Engineering and Management*, CIBSE Guide M.

H10. PEOPLE

H10.1 Controls

Excellent guidance on developing sensible control strategies for occupants can be found in the BCIA guide *Controls for End Users: A Guide for Good Design and Implementation.*[39] Key issues addressed include the following:

- What is the control for?
- Who is the control for?
- Where should the controls be located?
- Is the design intent clear to end users?
- Is the system status clear to users?
- Are controls well integrated and energy efficient?
- How long should user override last?

The guide also presents examples of controls and ranks them from poor to excellent against six usability criteria:

- Clarity of purpose.
- Intuitive switching.
- Labelling and annotation.
- Ease of use.
- Indication of system response.
- Degree of fine control.

H10.2 Engagement with occupants

An anecdote from Australia reveals the benefit of engaging with occupants during the design process and not making assumptions that people aren't interested in shaping how their building works:[40]

'During a workshop early in the design process, the senior managers admitted they didn't really know how their staff would react to a mixed mode office. The design team set up another meeting and this time the managers' PAs came along, each bringing two friends from the office. This user group became very excited by the possibilities of their new building and took it upon themselves to make it work.

They set up workshops in each department and came up with strategies to ensure all staff were engaged. They set about making a number of small changes in their current behaviours to prepare them for the new behaviours – they increased air-conditioning set points, modified the company's dress code and initiated a host of environmental initiatives that the whole company became involved in. They now have a very successful mixed-mode building – and their bosses didn't think they'd be interested!'

H10.2 Building user guides

For examples of the contents of Building User Guides, refer to the Technical Manual of ratings tools such as BREEAM, LEED and Green Star. Producing simple (one page) guides than can be fixed to notice boards or on small panels next to controls can also be effective. Making systems as intuitive as possible should be the ultimate aim – does anyone read a manual to work an iPod?

H10.3 Green leases

Green leases are used by a number of government departments in Australia but are yet to really take off elsewhere. The main purpose of a green lease is to get landlords and tenants to work together to reduce energy and other environmental impacts. To do this they need to talk to each other, which sounds obvious, but when was the last time you had a conversation with your landlord about reducing either your energy bill, or the energy component of the landlord's service charge? Refer to section L.6 in Appendix L for more details on green leases.

Notes

All websites were accessed on 25 May 2013 unless noted otherwise. Information papers referenced are available to download from www.wholecarbonfootprint.com.

1. *Chapter 16: Human eye sensitivity and photometric quantities, Light Emitting Diodes*, Second edition by E. F. Schubert (Cambridge University Press, 2006). www.ecse.rpi.edu/~schubert/Light-Emitting-Diodes-dot-org

2. ASHRAE Guide 55 and ISO7730 use similar approaches for conditioned spaces. The ASHRAE guide also makes reference to adaptive thermal comfort in naturally ventilated spaces, which is also described in CIBSE Guide A. Refer to Information Paper 17 - Thermal comfort standards for further details.

3. www.hse.gov.uk/temperature/thermal/explained..

4. CIBSE Guide A, section 1.4.2.5 states: 'Table 1.7 recommends 25°C as an acceptable summer indoor design operative temperature for non-air conditioned office buildings, and Table 1.8 recommends limiting the expected occurrence of operative temperatures above 28°C to 1% of the annual occupied period (e.g. around 25–30 hours). Between 25°C and 28°C increasing numbers of people may feel hot, uncomfortable and show lower productivity. Indoor operative temperatures that stay at or over 28°C for long periods of the day will, except during prolonged hot spells, result in dissatisfaction for many occupants.'

5. The UK Health and Safety at Work Act 1974 requires that for workplaces where the activity is mainly sedentary (e.g. offices), the temperature should normally be at least 16 °C. CIBSE Guide A Figure 1.9 suggests a temperature of around 19°C as the minimum for an office space.

6. *Designing User-Friendly Passive Buildings* by Ania Hampton, EDG 67 AH, May 2011. www.environmentdesignguide.com.au

7. Summarised from a presentation by Sustainability Victoria at AIRAH's Achieving the Green Seminar, Melbourne, September 2012.

8. *Japan promotes 'Super Cool Biz' energy saving campaign*, 1 June 2011, BBC website www.bbc.co.uk/news/business-13620900. Examples of clothing ranges can be found at www.uniqlo.com/jp/store/feature/uq/coolbiz/men/.

9. For further details on different blind options, refer to Information Paper 16 – Types of blinds for offices.

10. The SHGC includes both the solar energy directly transmitted through the glass, plus the solar energy absorbed by the glass and subsequently convected and thermally radiated inwards. The shading coefficient (SC) is sometimes used and is the ratio of solar heat gain through the glass relative to that through 3mm clear glass at normal incidence. 3 mm clear glass has a SC =1 and SHGC = 0.87.

11. Refer to *Human Factors in Lighting*, 2nd Edition, by Peter R. Boyce, for further information.

12. The current German workplace regulations no longer specify a strict limit. However, BGR 131-1 *Natural and artificial lighting of work places, Part 1: practical guides for entrepreneurs* (October 2008) states that wherever possible, jobs should be illuminated with natural light. Daylight has quality features which cannot be matched in their entirety by artificial lighting. It also notes that an adequate line of sight to the outside is important for humans. Workplace Guideline ASR 7/1 *Visual connection to the outside* states that a visual connection to the outside must be provided at eye level through windows, transparent doors or walls. Rules are given regarding the minimum area, size and sill height for windows related to room size and depth.

13. Refer to Information Paper 36 – Useful daylight index for further details.

14. For further details, refer to www.econtrol-glas.de/en/home/. Another type of technology is liquid crystal glass. This is opaque and requires a constant electrical current to become clear and is therefore not suited to solar control of facades – electricity is consumed to allow daylight in and views out. Example applications for this glass can be found at www.interpane.com/ipaview_cf_113.html?sprache=englisch.

15. *Dynamic Daylight Glare Evaluation*, Jan Wienold, Eleventh International IBPSA Conference, Glasgow, July 27-30, 2009.

16. Further details of the analysis and results can be found in Information Paper 19 - Facade modelling - daylight v thermal performance.

17. CIBSE Guide B, section 2.4.7 states that: 'As the cooling provided is a function of the temperature difference between the thermal mass and the space, night cooling is most suited to buildings where the temperatures are permitted to rise during peak summer conditions. In the UK, night-cooled solutions can provide up to 50–60 W/m^2.' In urban environments, the heat island effect, caused by heat absorbed by dark surfaces (roads, pavements and buildings) can increase night time temperatures compared to rural temperatures. This can reduce the cooling (recharging) of thermal mass at night.

18. Study reported in Natural Ventilation News, Issue 5, January 2012, the newsletter of the CIBSE Natural Ventilation Group.

19. *How to improve energy efficiency of fans for air handling units* by Nejc Brelih, REHVA Journal, February 2012. This article also references the EU Commission Regulation (EU) No 327/2011 of 30 March 2011 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to Ecodesign requirements for fans driven by motors with an electric input power between 125 W and 500 kW.

20. Study by ECiS AB (Energy Concept in Sweden) – refer to note 18.

21. CIBSE Guide B, section 2.4.4.3 provides a costed example of two ducted systems designed to provide 2000 l/s of air – one at high velocity (small ducts) and one at low velocity (larger ducts). The fan efficiency was the same for both. While the low velocity system has a higher capital cost (by approximately 30%), the electricity consumption of the fans was reduced by 70%. The payback was less than 5 years.

22. Improving ventilation effectiveness allows indoor air quality to be improved without the need for higher air changes in the building, avoiding the capital costs and energy consumption associated with increasing the ventilation rates. Refer to *Ventilation Effectiveness*, REHVA Guidebook No. 2.

23. Cundall worked closely with UCI in Australia during the development of the task air system, which won Innovation of the Year at the CIBSE Building Services Awards in 2009. www.taskair.net has more details of the system and case studies. Refer also to *Designing personal micro-climates with workstation based air conditioning*, Rob Lord, Cundall, AIRAH Ecolibrium, October 2008.

24. *Utilisation of thermal mass in non-residential buildings* by Tom De Saulles, The Concrete Centre, 2006.

25. Data from DuPont for Energain. http://energain.co.uk

26. *CPD module 1: phase change materials*, Building Design, 15/2/2013. www.bdonline.co.uk

27. Refer to Information Paper 21 – Chiller energy efficiency for further details.

28. If the server room cooling system is connected to the primary chilled water circuit then this can cause the building's main chillers to run 24/7 at inefficient loads. This situation occurred with a small server room in a 50 storey office building in Melbourne – the owners couldn't understand why the building's NABERS energy rating was so poor. A third energy audit finally located the problem and the server room was then connected to the secondary cooling circuit.

29. The typical values for lamp efficacy are taken from *The Illustrated Guide to Electrical Building Services*, BSRIA BG 5/2005. Lamp life is based on a typical manufacturer's data in July 2012.

30. Data taken from IEA Fact Sheet: *Standby power use and the IEA '1-watt Plan'*, April 2007.

31. *The Low-Hanging Fruit ... That Keeps Growing Back*, blog by David Goldstein, 26 Aug 2011. http://switchboard.nrdc.org/blogs/dgoldstein/post_1.html

32. In 2007 the US EPA reported an average PUE of 2.0 and estimated best practice performance of 1.4 by 2011. www.energystar.gov/ia/partners/prod_development/downloads/EPA_Datacenter_Report_Congress_Final1.pdf.

Google data centres had a PUE of around 1.2 in 2011. www.google.com/corporate/datacenter/efficiency-measurements.html.

33. *Reducing the Energy Consumption of Data Centres*, NABERS Fact Sheet. www.nabers.gov.au

34. *Power, Pollution and the Internet* by James Glanz, New York Times, 22 September 2012 www.nytimes.com/2012/09/23/technology/data-centers-waste-vast-amounts-of-energy-belying-industry-image.html?pagewanted=all&_r=1&

35. The Chartered Institute for IT has developed an energy rating system for data centres, *Certified Energy Efficient Datacentre Award (CEEDA)*, to provide audited evidence that an organisation is implementing best practices. www.ceeda-award.org. Other tools and rating schemes by other organisations are also being developed.

36. *E4: Energy Efficient Elevators and Escalators*, a report by ISR University of Coimbra (Portugal) for Intelligent Energy Europe, March 2010. www.e4project.eu/documenti/wp6/E4-WP6-Brochure.pdf.

37. *Model Commissioning Plan*, by S. Deramchi and G. Hawkins, BSRIA BG 8/2009.

38. Details can be found at www.usablebuildings.co.uk/WebGuideOSM/index.html

39. *Controls for End Users: A guide for good design and implementation* by Bill Bordass, Adrian Leaman, and Roderic Bunn, British Controls Industry Association, BCIA 1/2007. Available for free from www.bsria.co.uk/bookshop.

40. Refer to note 6.