Ventilation and cooling option appraisal – a client's guide

- Do you really need air-conditioning?
- Learn how much natural ventilation can do
- Understand the jargon

BEST PRACTICE PROGRAMME

ENERGY EFFICIENCY

GOOD PRACTICE GUIDE 290

CONTENTS

1 INTRODUCTION

Annual energy consumption of air-conditioning systems in the UK service sector is significant – 55 PJ (1994) with an energy cost of £830 million, leading to around 9 million tonnes of carbon dioxide (CO_2) emissions.

In recent years there has been significant progress in the application of techniques that reduce the dependency on conventional air-conditioning – natural and passive ventilation, mixed-mode operation and low-energy cooling systems.

This Guide is intended for promoters, funders and building owners who are in the position of briefing a design team on their requirements for ventilating and air-conditioning systems. It provides an introduction to the available options, both for conventional systems and new 'green' designs. The focus of the Guide is on cooling and ventilation strategies that give value for money while ensuring:

- a good quality internal environment with which the occupants will be happy
- simple systems to meet the occupant requirement, systems which can be readily understood, managed and maintained
- the provision of systems which run in an energy-efficient manner and have the lowest possible environmental impact (which usually results in the lowest energy costs).

If the 'building envelope' has favourable characteristics, the mechanical services design may be simplified. This benefits the client, as the mechanical plant will be smaller and less complex; hence it will have a lower capital cost and should run in a more stable and energy-efficient manner, helping to keep tenant complaints to a minimum. Plant depreciation will also be less, and replacement will be on a smaller scale. Furthermore, a simpler plant is easier to operate and maintain correctly.

It is recommended that the design team carries out a detailed option appraisal of the possible cooling and ventilation strategies. The relative merits of the potential solutions can then be compared in a systematic way. The Guide provides a checklist of issues that you need to discuss with your design team, to achieve, in an energy-efficient way, your requirements for a functional and comfortable building within the capital and operational budgets.

The Guide takes you through the following stages:

- parameters used for option appraisal and key design questions
- a description of the available ventilation and cooling strategies
- a table of comparative data for these ventilation and cooling strategies (see pages 24 to 29).

A technically more detailed Guide (GPG 291[1]) has been written in parallel with this Guide, and, although primarily aimed at designers, it is recommended to those who wish to appreciate in more technical detail the issues raised in this Guide.

Another Guide (GPG 285[2]) encourages you to consider the wider business benefits of other energy efficiency measures, as well as those relating to ventilation and cooling.

OCCUPANTS

The ventilation and cooling strategy should be driven primarily by the occupier's business requirements. It is important that the needs of the building users are understood in order that the brief can be developed with the design team to determine:

- what activities will be accommodated
- the heat gains of the occupants
- the process load or office equipment heat gain
- occupancy hours
- the required quality of the internal environment
- the occupants' need for local control of the conditions within the space
- the management and maintenance expertise held by in-house staff.

These are all largely fixed by the nature of the occupier's current and expected business and activities.

INTRODUCTION

BUILDING ENVELOPE

The design of the mechanical services pivots on the quality of the building envelope, including the building shape, windows, mass, etc. If the thermal characteristics are good then the services engineer's job is greatly simplified and the client benefits too. This is because the plant will be uncomplicated, and hence generally easier to understand, and more likely to be operated and maintained correctly.

The benefits for the developer will be a building with less complex environmental services together with a lower capital cost and robust energy-efficient features which will add to the sale and rental value of the building. These buildings are simpler to lease and re-lease for the landlord, and for the occupant they offer a more responsive environment and lower running costs. The benefit to everyone is a building with a considerable contribution to a sustainable resources policy.

The building envelope should be the main climatic modifier leaving the plant to make the final adjustments to the internal conditions. This approach has to be stated in the brief to the design team so that it is embodied in all stages from sketch design onwards. It may also be possible to take advantage of existing building envelope characteristics when retrofitting mechanical services.

Figure 1 BRE Environmental Building – showing ventilation stacks and external solar shading

INTRODUCTION

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BUILDING SERVICES OPTIONS

Only when the needs of the occupants have been identified, and the impact of the building envelope has been fully optimised, should the building services be considered in depth. In many buildings, heat gains need to be dispersed in order to achieve comfort. There are two routes to bring this about: passive cooling and mechanical cooling. Passsive cooling means taking advantage of the building characteristics, natural forces and changing external conditions; it is generally achieved as part of a ventilation strategy. Mechanical cooling means using mechanically driven plant to generate the cooling. The remainder of this Guide discusses all the options available, and their interaction with the building envelope and occupants.

2 AN OPTION APPRAISAL

An option appraisal is the evaluation of a range of possible systems in order to obtain the optimum solution. More detailed information on option appraisal of ventilation and cooling systems, written for the building services engineer, can be found in GPG 291[1].

The optimum solution is obtained by striking a balance between user requirements, financial constraints, site constraints and the design of the building envelope and its services.

A comparison should be carried out for the following criteria:

- capital and operating costs
- design lifetime of equipment
- required quality of the internal environment
- environmental policy
- occupant expectation
- management and maintenance issues
- flexibility for spatial layout changes or occupancy use.

The benefits of appraising all the options should ensure that both the client and the occupants have the most appropriate building and environmental system for all their requirements. For more detailed information on carrying out financial appraisals consult GPG 165[3]. Further thoughts on the relationship between these parameters and the benefits to the occupier's business can be found in GPG 285[2].

SPECIFYING BY BENCHMARKS

Part of the design team's brief should address the performance of a building with reference to published benchmarks, an example of which is outlined in table 1.

Parameter	Benchmark
Temperature bands	Loose fit – no more than 1% of occupied hours above 28°C Loose control – heat up to 21°C winter, cool down only to 23°C summer
References	*GIR 30. A performance specification for the Energy Efficient Office of the Future*[4] *CIBSE Guide A. Environmental design*[5]
Energy	Building to be capable of performing to 'good practice' energy benchmarks
References	*Energy Efficiency Best Practice programme – Energy Consumption Guides* *Energy Efficiency Best Practice programme – Energy Efficiency in Buildings series*
Environmental performance	BRE Environmental Assessment Method (BREEAM)
References	*BR350. BREEAM 98 for offices*[6] *BREEAM 2/91. An environmental assessment for new superstores and supermarkets*[7] *BREEAM/New Industrial Units. Version 5/93. An environmental assessment for new industrial, warehousing and non-food retail units*[8] *BR278. Environmental Standard: homes for a greener world*[9]

Table 1 Benchmark examples for specifying building performance

3 KEY QUESTIONS

The decision whether a passive or a mechanical cooling approach is required can be determined readily by a series of relatively straightforward questions about the building and its internal environment. Figure 2 presents a flow chart summarising these questions; the options mentioned at the foot of the figure are discussed in this Guide and in the accompanying checklists. The flow chart also indicates whether comfort cooling or full air-conditioning is required.

The installation of a more complex system than one determined by this flow chart should be recognised as a marketing decision rather than an engineering one.

IS CLOSE CONTROL OF HUMIDITY NEEDED?

Humidity is measured in terms of relative humidity (RH). In general, people find the humidity to be acceptable within the ranges of 40% to 70% RH. Most buildings will float within this range without humidification plant, which would consume significant energy in winter. If the humidity is too low then problems can occur with static electricity (<40% RH) and health problems associated with the drying of the respiratory tract (<30% RH).

DOES THE BUILDING HAVE TO BE SEALED AGAINST NOISE OR POLLUTION?

Although noise and pollution, for instance caused by traffic, can be a nuisance, it is often possible to ventilate the building from the back or another façade where the air quality is better. People also prefer being able to open windows, so sealing the building should be avoided if possible.

ARE THERE HIGH INTERNAL HEAT GAINS?

Internal heat gains are caused by the occupancy density, computers and other machine and lighting loads; it is usually worth considering reducing them. For example, there are many energy-efficient lighting devices on the market – high-efficacy lamps, high-efficiency luminaires and lighting controls. If these loads cannot be reduced then some form of cooling will be required to the space. Natural ventilation may not be adequate.

WILL IT BE ACCEPTABLE FOR THE OCCUPIED SPACE TO EXCEED 28ºC FOR A FEW HOURS EACH YEAR?

Comfort depends on occupant activities and other conditions in the space, such as air movement, radiant temperature and humidity. It is sometimes argued that high temperatures and high humidity reduce productivity; however, this should be balanced against the infrequency of these extreme conditions. A well-designed building envelope in the UK can restrict peak space temperatures to about 28ºC without the need to resort to mechanical cooling. If this temperature swing is acceptable to the occupants then a low-energy naturally ventilated solution may be a viable option.

Such temperature swings have been found to be acceptable in a number of buildings; an example is the refurbished Walton Hall administrative office at the Open University (see GPCS 308).

The points raised above should be addressed in conjunction with various management and maintenance issues. In particular:

- the building and its system should be responsive to user needs and have the capacity to rectify the environmental conditions when the occupants become uncomfortable
- occupants have an increased tolerance to higher temperatures where they are able to take some personal action to ameliorate their situation, such as opening windows, adjusting controls, etc
- systems should be explained to the occupants so that they can use them to provide comfort
- systems should be maintained correctly.

The table in the appendix (pages 24 to 29) contains a comparison of a range of cooling strategies varying from natural ventilation to mechanical and low-energy cooling systems which are detailed in sections 4 and 5 of this Guide.

KEY QUESTIONS

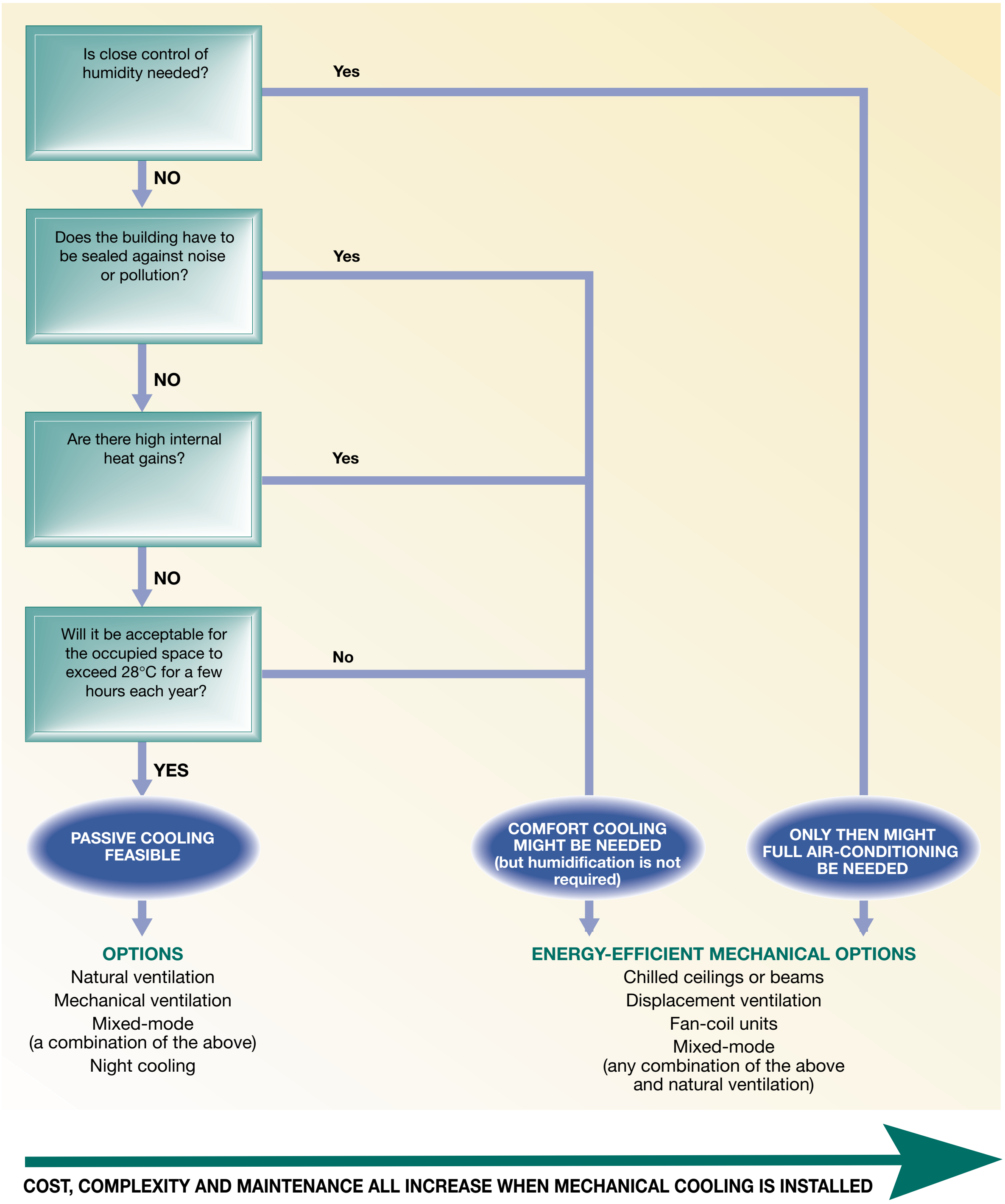


Figure 2 Key questions

4 PASSIVE COOLING STRATEGIES

Figure 3 The central atrium at Powergen's Head Office allows for natural ventilation via motorised openings at high level

Passive cooling is achieved by using ventilation, coupled with the configuration and thermal properties of the building. In addition to cooling, ventilation is necessary to provide for respiration of the occupants, and also to control the level of pollutants inside a building, such as odours or tobacco smoke.

The majority of the UK building stock is naturally ventilated using openable windows. Although this normally provides only a coarse control of the flow of air, the occupants tend to prefer these buildings to air-conditioned ones because they:

- understand how they work
- know what to do to get an immediate response
- have a measure of individual control.

Should a more predictable system be required, before opting for a mechanical ventilation system (section 4.2), opportunities for a mixed-mode approach (section 4.3) should be examined. The appendix includes an indication of the levels of environmental control that are possible with different ventilation and cooling systems. Environmental control is rarely required to high tolerances – offices do not need to be controlled as tightly as operating theatres. Generally, tighter control demands greater complexity of design and higher capital and operating cost; the client should consult with the designer to determine what level is required for the actual use of the building.

4.1 NATURAL VENTILATION

Natural ventilation relies on moving air through a building under the natural forces caused by outside wind pressure and the buoyancy effects of temperature differences. Air paths need to be simple and generous as wind and buoyancy pressures are low.

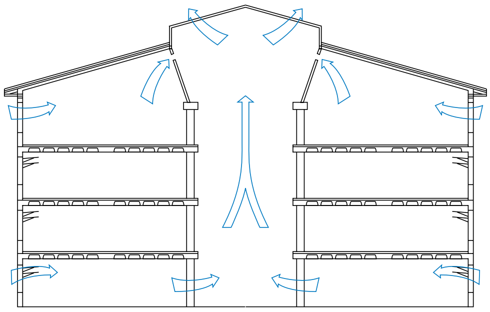


Figure 4 Detail of stack-induced crossflow ventilation

As the ultimate passive cooling system, natural ventilation delivers low energy and low running costs but the predictability of the thermal environment may be lower than that achieved by mechanical means.

The three main categories of natural ventilation systems are listed below and illustrated in figure 7 on page 12.

- Openable windows (single-sided or cross ventilation) – this is the simplest form of natural ventilation and has the benefit of allowing the occupants control over their environment.
- Motorised vent openings (single-sided or cross ventilation) – ideally coupled with night cooling, a technique which uses the building mass to offset overheating during the day (see section 5.1.6).
- Stack ventilation and wind scoops – sophisticated natural ventilation techniques, often integrated with structural design, can be very effective and elegantly simple. They generally have to be designed into new buildings.

Figure 5 Solar chimney doubling as corner staircase at the Inland Revenue Headquarters, Nottingham

PASSIVE COOLING STRATEGIES

4.1.1 Natural ventilation option appraisal

Capital and operating costs

- Capital costs of naturally ventilated buildings will be lower than those for air-conditioned buildings.
- Savings can be channelled into a higher specification for the building envelope, for example, increased solar shading and higher levels of insulation.
- Natural ventilation systems offer one of the lowest energy consumptions (see appendix). Operating costs are generally lower than those for air-conditioned buildings.
- However, during the heating season, occupants should be discouraged from controlling temperatures by using excessive natural ventilation instead of thermostats, as this could waste heating energy.
- Plant space requirements for natural ventilation systems are minimal, leaving considerably more lettable area than is the case with mechanically ventilated or air-conditioned buildings.

Absolute quality of the internal environment

As may be expected, the internal environment of buildings utilising natural ventilation is affected by external conditions to a greater degree than those utilising mechanical ventilation. Internal temperatures may mirror external air temperatures (although the use of thermal mass can offer the opportunity for night cooling, see page 6 and section 5.1.6). Open windows may be unacceptable if the external environment is noisy (eg building adjacent to a busy road), polluted or features a high pollen count. It is important that there is sufficient airflow for odour control (especially as natural ventilation offers no control over the internal humidity).

Minimum fresh air rates are recommended for mechanical ventilation for odour control because the rates can be controlled. Although it is not possible to ensure a predictable fresh air rate with natural ventilation, owing to the random nature of the wind, it is feasible to design for adequate natural ventilation. The subject is dealt with in more depth in the NatVent Guide[10].

Environmental issues

- Naturally ventilated buildings incur relatively low energy consumptions, particularly for electrical plant.
- CO_2 emissions should be very low, thus reducing the environmental impact of the building.

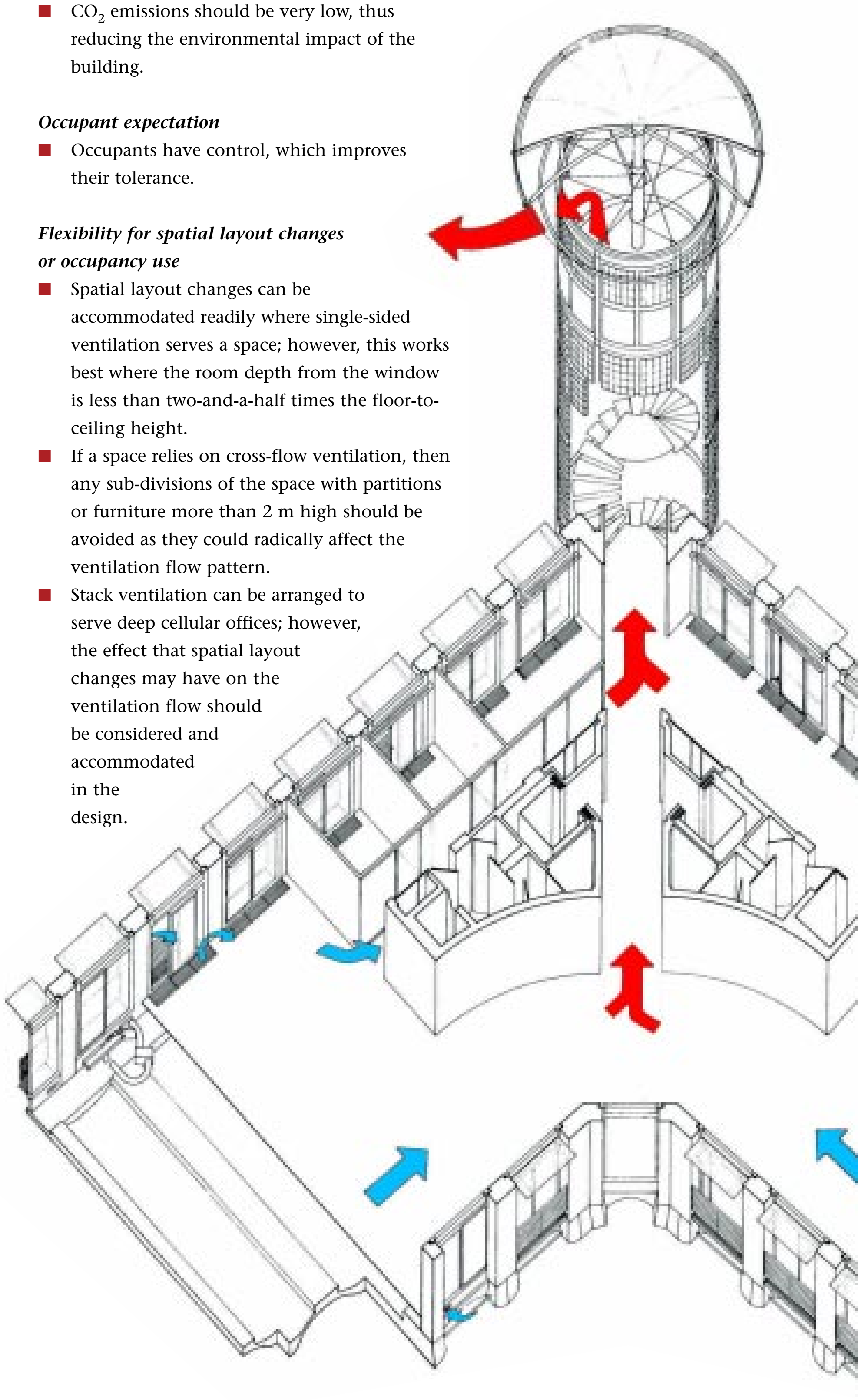
Occupant expectation

- Occupants have control, which improves their tolerance.

Flexibility for spatial layout changes or occupancy use

- Spatial layout changes can be accommodated readily where single-sided ventilation serves a space; however, this works best where the room depth from the window is less than two-and-a-half times the floor-to-ceiling height.
- If a space relies on cross-flow ventilation, then any sub-divisions of the space with partitions or furniture more than 2 m high should be avoided as they could radically affect the ventilation flow pattern.
- Stack ventilation can be arranged to serve deep cellular offices; however, the effect that spatial layout changes may have on the ventilation flow should be considered and accommodated in the design.

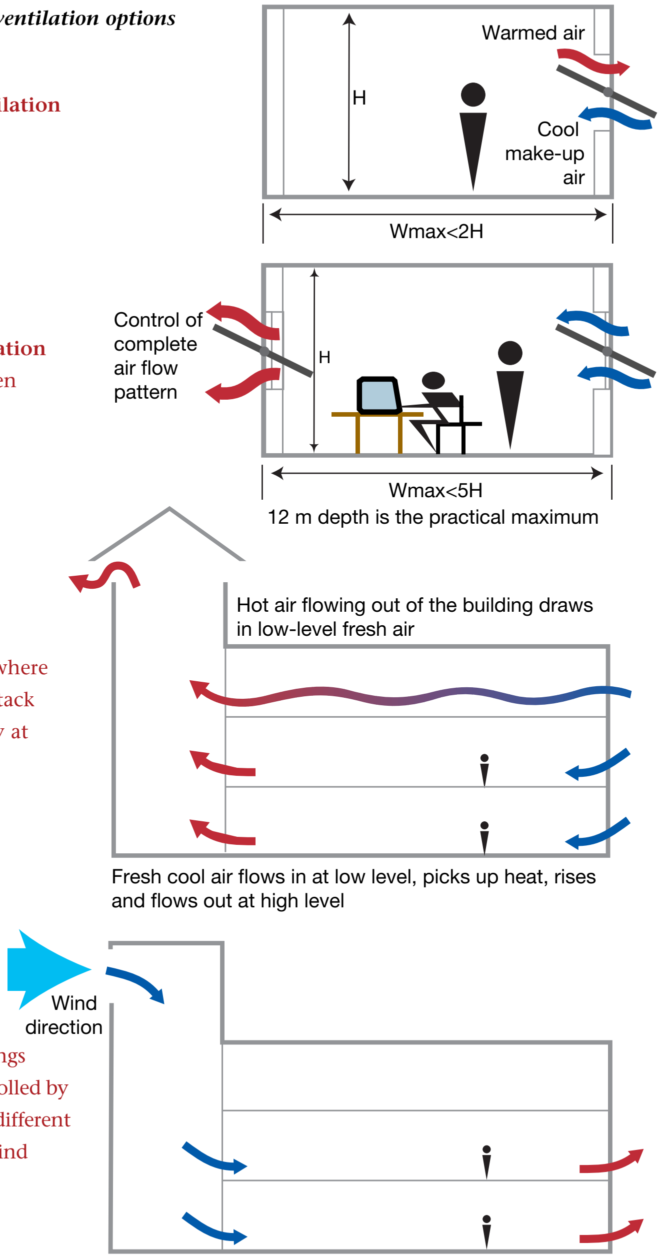
Figure 6 Detail of airflow for the solar chimney stack-induced cross ventilation



PASSIVE COOLING STRATEGIES

- Security is an issue when designing natural ventilation. It is generally undesirable to have accessible windows open at night. However, openings for night cooling can be designed to maintain building security.

Figure 7 Natural ventilation options



Single-sided ventilation

Cross-flow ventilation
Usually wind driven

Stack ventilation
Buoyancy driven where density at top of stack is less than density at low level

Wind scoop
Tower needs openings on each side, controlled by louvres, to exploit different wind directions. Wind forces may oppose buoyancy forces

These factors can readily be dealt with if they are borne in mind during initial design, subsequent fit-out and future changes.

4.2 MECHANICAL VENTILATION

Mechanical ventilation systems have motorised fans to supply and/or extract air to and from the building.

Mechanical ventilation systems can maintain specific internal temperatures more readily than natural ventilation systems, which function under variable wind and buoyancy forces.

The three main categories of mechanical ventilation are:

- extract only
- supply only
- supply and extract.

See figure 8 and appendix on pages 24-30 for more information.

An extract-only system might be installed where there is a particular source of internal pollution to be dealt with. A supply-only system can provide filtered air, to dilute pollutants in the building to the desired level. Pressurisation in this manner will reduce any infiltration of unfiltered air into the building.

4.2.1 Mechanical ventilation option appraisal

Capital and operating costs

- The capital costs are higher than for naturally ventilated systems due to the additional expense of air-handling plant and distribution ductwork.
- The operating costs are higher due to the electrical energy usage for the system fans – this should be minimised by designing to low pressure drops and operating only when absolutely necessary.
- The energy to heat the supply air can be reduced by using devices that recover heat from the exhaust air – recuperators, thermal wheels and run-around coils. However, this saving must be balanced against the additional electricity cost caused by the increased resistance to air flow that these devices present.
- The air-handling plant will occupy considerably more space than natural ventilation would have done, thus reducing the net-to-gross floor area ratio.

PASSIVE COOLING STRATEGIES

- Unlike natural ventilation, the size of the air paths can be reduced as the pressure drop is not as critical. The designer should be asked to design to acknowledged 'specific fan power' benchmarks to minimise distribution system pressure drops.

Quality of the internal environment

- These systems can be designed to provide ventilation and passive cooling in a predictable way and are not affected by the vagaries of wind conditions.
- They can provide a filtered supply of clean air with low levels of particulates.
- Noise transmission from outside or within the building can be avoided by building in sound attenuators.
- Humidified air can be distributed in a controlled way.

Environmental issues

- More electrical energy is used than with naturally ventilated systems, hence the CO_2 emissions will be higher and the building will have a greater environmental impact.
- Good design of the air distribution system will minimise the additional fan energy, eg low-pressure drop air paths, high-efficiency fans and variable-speed motors.
- Where humidification is found to be really necessary, humidifier choice will influence internal environmental quality and energy consumption.

Occupant expectation

- Occupants do not like loss of control over the ventilation; hence they generally do not like buildings where windows cannot be opened. Also, where the building is sealed, their expectations of the internal environment increase and there is less tolerance when a system fails.

Management and maintenance issues

- There is more plant than with naturally ventilated systems, eg fans and filters; hence maintenance costs are higher. In addition, more sophisticated systems have even greater maintenance requirements, eg those with heat recovery devices or humidifiers.

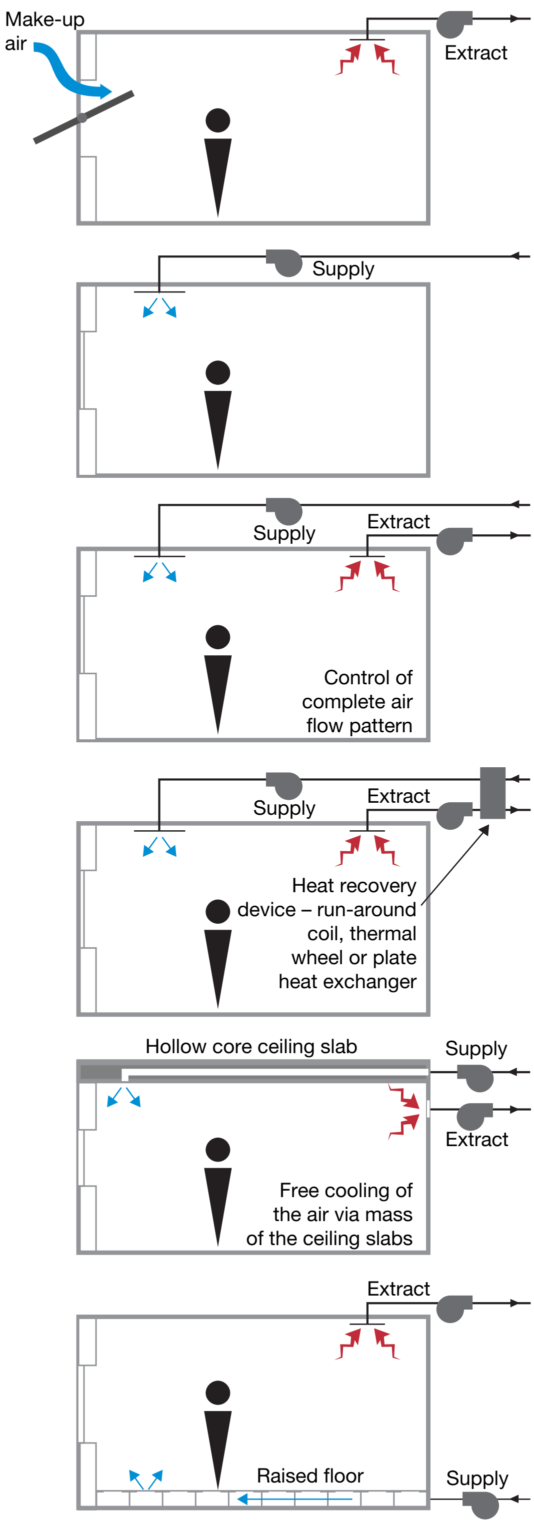


Figure 8 Mechanical ventilation options

a) Extract only – can be a local system or ducted

b) Supply only – pressurises room to avoid infiltration

c) Supply and extract balanced ventilation

d) Supply and extract with heat recovery

e) Hollow core supply – supply air delivered through ceiling slab

f) Ventilated floor void

PASSIVE COOLING STRATEGIES

- Ductwork cleaning could become necessary under health and safety regulations and this may have considerable cost and design implications.

Flexibility for changes in layout or organisational use

- The security of the building need not be impaired.
- Floor supply systems give good flexibility in accommodating spatial layout changes – floor outlets can be moved to match occupancy patterns. High-level ducted systems have reasonable flexibility. However, it is important to check during later fit-out or refurbishment that air flow patterns which are necessary to provide comfort are not compromised.

4.2.2 Hollow core systems

Thermal mass in the building can be used to absorb heat. The effectiveness of the mass can be increased by passing air through the structure. This may take the form of hollow core construction (see figure 9), which increases the area of exposed mass. These systems usually require mechanical ventilation to overcome the higher pressure drops through the air paths.

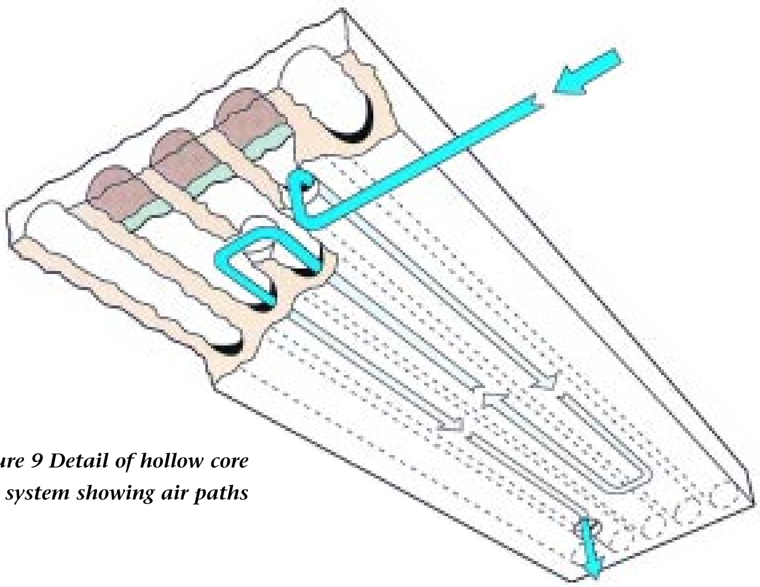


Figure 9 Detail of hollow core system showing air paths

4.3 MIXED-MODE OPERATION

There are a number of examples where the building can be operated with a mixture of natural and mechanical ventilation systems. This is referred to as mixed-mode, and aims to maximise the benefits of utilising both systems. Typically, it offers the benefits of natural ventilation, but introduces mechanical ventilation and/or mechanical cooling when or where natural ventilation is inadequate to provide comfort.

The appendix (pages 24-30), summarises some mixed-mode system options. There are two main operational techniques. These are the changeover method and zoned systems.

The changeover method uses different systems depending on the season. For instance, during the winter periods, the building could be sealed. Mechanical ventilation could then be used to supply minimum fresh air and exhaust air heat recovery could be used to minimise heating consumption and, as a consequence, the impact on the environment would be minimised.

For the spring and autumn seasons the building could be cooled by natural ventilation using outside air as necessary. For the summer mechanical cooling could be used if it is available; if not, the system would remain on natural ventilation during occupation while perhaps using mechanical ventilation for night-time cooling.

Problems can be caused with occupants opening windows if they are not clearly informed as to when the system changes from mechanical to natural ventilation are programmed to take place. However, there are psychological advantages to allowing occupants control over window opening for at least part of the year.

Zoned systems can have, for example, natural ventilation on the perimeter and mechanical ventilation in the core. This operational mode could also be used where there are specific areas with high heat gain.

4.3.1 Mixed-mode option appraisal

A detailed appraisal should be carried out for the mixed-mode option.

It might be thought that mixed-mode systems would have higher capital costs as two systems are specified. However, a judicious choice of systems can reduce system costs, for example using mechanical ventilation for the small volume of wintertime fresh air and natural ventilation at other times would avoid large air-handling plant and ductwork.

Mixed-mode systems offer the security of improved environmental conditions by using mechanical ventilation/cooling when needed without having to operate fans and chillers throughout the year.

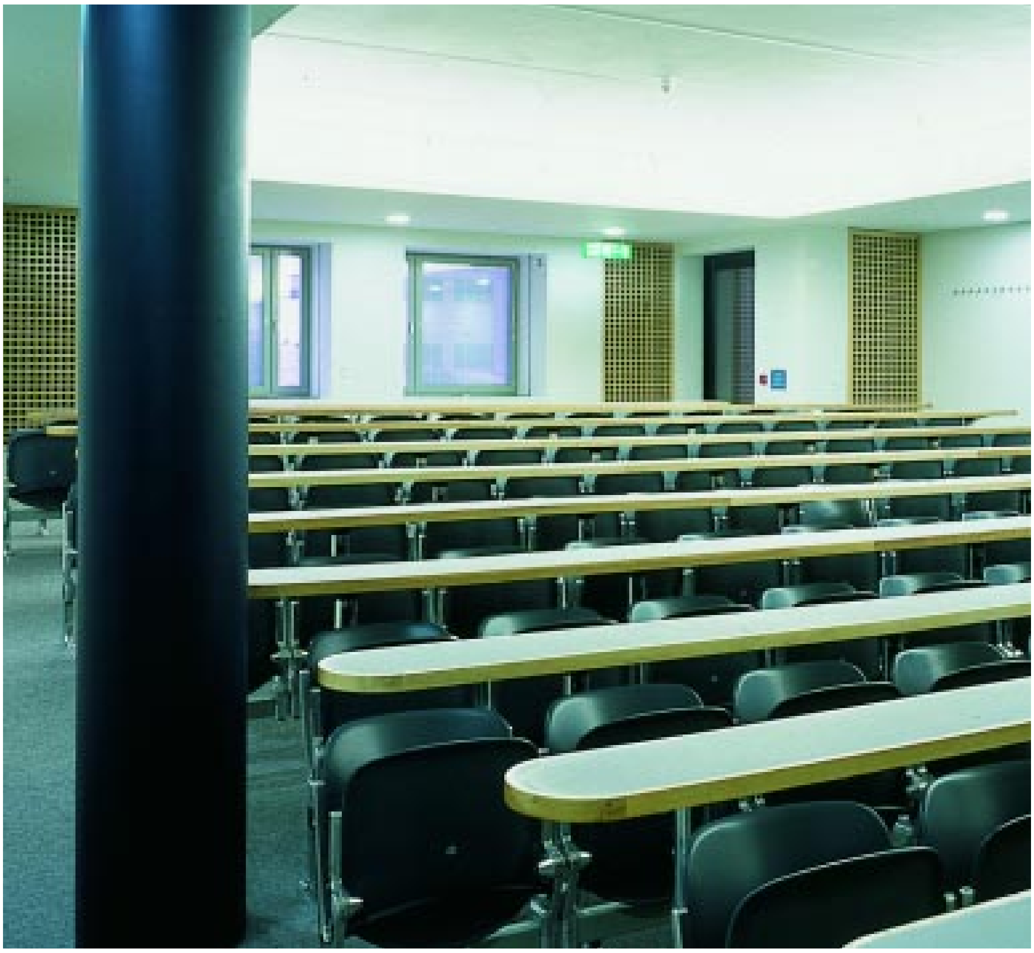


Figure 10 Interior of a hollow core mixed-mode building

5 MECHANICAL COOLING STRATEGIES

For applications where tight environmental control is required, mechanical cooling systems have to be considered. However, a typical air-conditioned building has double the energy cost and associated CO_2 emissions of a naturally ventilated, heated building. It will also have increased capital and maintenance costs.

The core of all mechanical cooling systems is the heat pump, a device that moves heat from one place to another. Thus, one end of the heat pump is cooled and the other end heated. In essence, this is the same as a domestic refrigerator (where heat is pumped from inside the cabinet to outside), but on a larger scale. If the purpose is to create cooling, the surplus heat has to be rejected. This takes place either directly at an air-cooled pipe coil (see below), or via an intermediate 'condenser' water circuit at a cooling tower remote from the heat pump. In a central system, the heat pump is often called a 'chiller' or 'refrigeration machine'. In smaller systems it may be called an 'air-conditioner' or even a 'heat pump', particularly where the direction in which the heat can be pumped can be reversed.

The cold fluid provided by the heat pump can be either refrigerant (if there is only one place where cooling happens, generally in unitary systems) or 'chilled water' (where the cooling is needed at several places around the building, normally the case in centralised systems). Where chilled water is provided, pumps are needed to move it around the building to where cooling takes place.

The cooling generated by the heat pump has to be transferred into the air in the room where excess heat causes discomfort. The heat transfer often takes place at a 'pipe coil', which consists of rows of parallel pipes through which the cold fluid passes. Metal fins at right angles to the pipes aid the heat transfer from the air, which is usually blown over the coil by a fan. This fan can either be next to the coil or it might be at a more remote point of a ductwork system. The air over the coil then mixes with the air in the room, removing the excess heat by cooling it down and thus achieving thermal comfort.

The amount of cooling given to the space can be varied by changing either the temperature difference between the incoming air and the room, or by changing the volume of air entering the room, or both. There are limits on both these parameters, because surfaces in the coil which are too cold may get condensation on them, and large volumes of air may cause draughts and/or noise.

Fans used to move cool air around the building consume a major component of energy in conventional centralised air-conditioning and comfort cooling systems. The amount of energy used by chillers is generally much smaller than the fan energy in air-conditioned buildings in the UK.

The fan energy can be reduced by:

- asking for systems to be designed to a 'specific fan power' not exceeding 2 Watts per litre/sec – this means reducing the resistance to airflow through the ductwork, which in turn means making the ducts as large and as short as possible, and with smoothed rather than sharp bends
- use of efficient fans and motors
- fan speed control; this reduces the air flow at part load or part occupancy
- improving the ventilation effectiveness; for example, displacement ventilation will deal with specific areas of heat load rather than by conditioning the whole space.

The energy consumed by cooling systems can be reduced significantly by using chilled water or refrigerant instead of air as the medium to transport the 'coolth' around the building.

Systems which use some of the above features are described in the following section.

5.1 CONVENTIONAL SYSTEMS

There are three generic types of air-conditioning systems.

Unitary systems

Sometimes referred to as 'local' systems, they are commonly used to serve a single zone or small proportion of a building (see figure 11). Packaged air-conditioners have all their components in a

MECHANICAL COOLING STRATEGIES

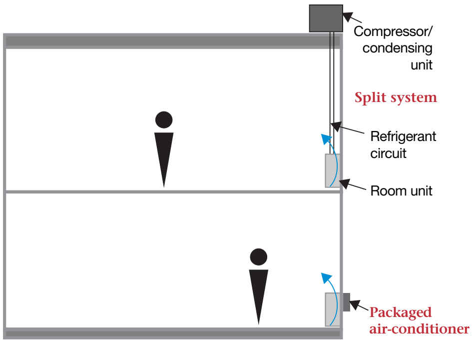


Figure 11 Unitary systems

single box, which can be installed ready tested. 'Split systems' separate the room units, with their fan and heating/cooling coils, from the compressor and condensing units. The latter noisy components can then be placed outside the building. The room units can be mounted in the wall or in an enclosure, or in the ceiling where they are commonly called cassettes.

Centralised systems

Cooling typically comes from large central chillers that generate chilled water, which is then pumped around the building through pipes to wherever cooling is needed. Boilers produce heat which is circulated around the building through another parallel piped system. Chillers, being heat pumps, produce heat that needs to be dumped, either direct from a coil attached to the chiller or through warm water sent to a remote cooling tower. Ventilation is provided from a central air-handling plant. All this plant is normally located in central plant rooms but may be roof-mounted (see figure 12). Heating and cooling is distributed to the occupied spaces by air ducts or water pipes with the local control of comfort undertaken by the terminal units, eg variable air volume boxes, fan coil units, induction units, etc. 'Free cooling', ie cooling achieved without running chiller plant, should always be considered, although it may require increased duct sizes and fan energy.

Part-centralised systems

The centralised part of these systems consists of a heat generator (boiler) and heat rejection through a cooling

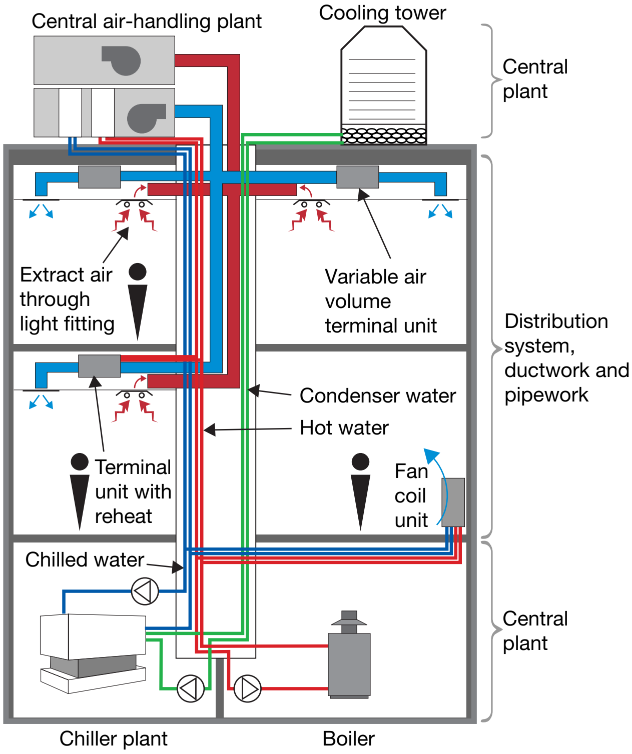


Figure 12 Composite centralised system

tower. The decentralised part typically consists of a number of unitary heat pumps connected by a common water circuit to the central plant (see figure 13 overleaf). These systems are often known by the trade name Versatemp. Each heat pump draws heat from, or rejects heat to, the water circuit and delivers this heat or 'coolth' to the space. Hence, heat can be recovered from spaces requiring cooling and delivered to spaces requiring heating. Generally, a central boiler plant provides supplementary heat when there is a net heating demand in the building, and all the units are extracting heat from the water circuit in winter. A central cooling tower is used for heat rejection during peak summer operation when there is a net cooling requirement for the building. Central air-handling plant generally provides the ventilation air needs (omitted from figure 13 for clarity).

Unitary systems are often installed piecemeal, to deal with cooling needs as they arise. Centralised and part-centralised systems have to be designed

MECHANICAL COOLING STRATEGIES

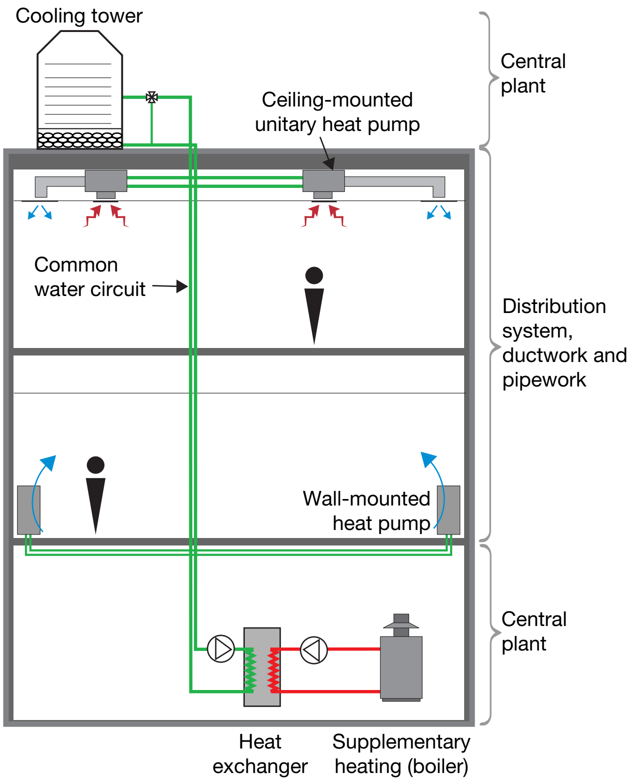


Figure 13 Part-centralised system

with the whole building in mind. They can benefit from economies of scale and diversity where not all parts of the building need maximum cooling at the same time. It is generally easier to apply to such systems novel cooling methods and energy efficiency measures, such as free cooling. Nevertheless, unitary systems have a role in large buildings where some areas need cooling for a different period from the rest of the building. For example, their use can allow the main centralised system to be turned off outside working hours.

5.1.1 Variable air volume (VAV)

A VAV system is an example of a centralised system with air distribution. Cool air is generated centrally and distributed around the building to each zone.

The VAV terminal boxes for each zone vary the amount of cooled air delivered to each space in accordance with the local thermostat. When all the zones need less cooling, the volume of air required by the building as a whole is less, and the system reduces the output from the central fan. This results in significant savings in fan energy when compared to constant volume systems. Heating may be either by heating coils in the air supply ductwork or by a separate perimeter heating system. The system gives good multi-zone environmental control but its complexity makes this an expensive solution. Refer to the appendix for more details.

5.1.2 Four-pipe fan coil system

'Fan coil' refers to the terminal unit in or near each zone. The unit contains separate heating and cooling coils and a small fan to blow air from the room, through the coils and back into the room. The term 'four-pipe' indicates that each coil has a flow and return pipe served by the central plant.

The output of the terminal units is usually controlled by changing the flow rates of the chilled or heated water through the coils in accordance with a local thermostat. Alternatively, dampers can divert the air within the unit to vary the air flow over the coils. Even though modern fans are fairly quiet, generally the fan runs at constant speed as changing speed draws attention to it.

There are also 'two-pipe' systems which have only one coil and one pair of pipes from the central plant that either provide chilled or hot water according to the season. Changing from one to the other takes a number of hours to clear the pipe system. However, in the mild weather which prevails for much of the year in the UK, it is difficult for the controls to decide whether the coils should be heating or cooling, or indeed whether different parts of the same building need heating and cooling at the same time. Hence this system is not favoured where either heating or cooling may be required, although it may be applicable where only cooling is needed, for instance in the core of a building.

A central air plant is normally used to deliver a relatively small volume of ventilation air to each zone. The fan coil system uses water for the main distribution of heating and cooling around the

MECHANICAL COOLING STRATEGIES

building, so fan energy is less than with a central all-air system, and the amount of ductwork is significantly reduced. As a consequence, so is the space requirement for air-handling plant, risers and false ceiling or raised floor voids.

As with any system with a cold coil in the room space, moisture in the air may condense on the coil surface, so a condensate drainage system is generally provided. Routing this out of the building may prove awkward and has an associated capital cost.

5.1.3 Variable refrigerant flow (VRF)

Sometimes referred to by the trade name VRV, this is essentially a split system (see section 5.1, 'Unitary systems') where a number of room units are served by one external condensing unit. Typically, the units can heat or cool, and sometimes recover heat from one zone for another.

Distribution of heating or cooling is achieved with refrigerant circuits through which the flow is varied, rather than turned on and off as is commonly the case with split units. The refrigeration pipework is considerably smaller than air ducts or water pipes for the same heating or cooling capacity, and this simplifies distribution. However, there are other considerations when using refrigerant as a distribution medium – for instance, there is a maximum distance between room units and the external condensing unit and it is important to guard against refrigerant leakage into the occupied space.

5.1.4 Displacement ventilation system

This is an alternative to traditional mixing systems, where the incoming air dilutes the air in the room by encouraging a thorough mixture. Instead, air is supplied at floor level at a temperature that is slightly cooler than that of the bulk of the air in the room and at a very low velocity. The cool air flows across the floor until it meets a heat source (such as a person or a computer). It picks up heat and rises to the ceiling where it is extracted at an opening at high level (see figure 14a and the appendix for more details). Heat sources generally coincide with pollution sources, and thus pollutants are directly removed from the occupied part of the space and carried up to the ceiling to be extracted. These systems offer good ventilation effectiveness with a good-quality environment; less air is needed because pollutants are targeted by the airstream and extracted.

5.1.5 Static cooling systems – chilled ceilings and chilled beams

Static cooling systems consist of ceiling-mounted panels or pipes that are cooled by chilled water. They transfer their coolth to the space by radiation or natural convection, without using fans to encourage air movement; hence the term 'static'. Since they use water as the main medium for the distribution of cooling around the building, there will be considerable savings in fan energy. There are two principal forms of static cooling – chilled ceilings and chilled beams.

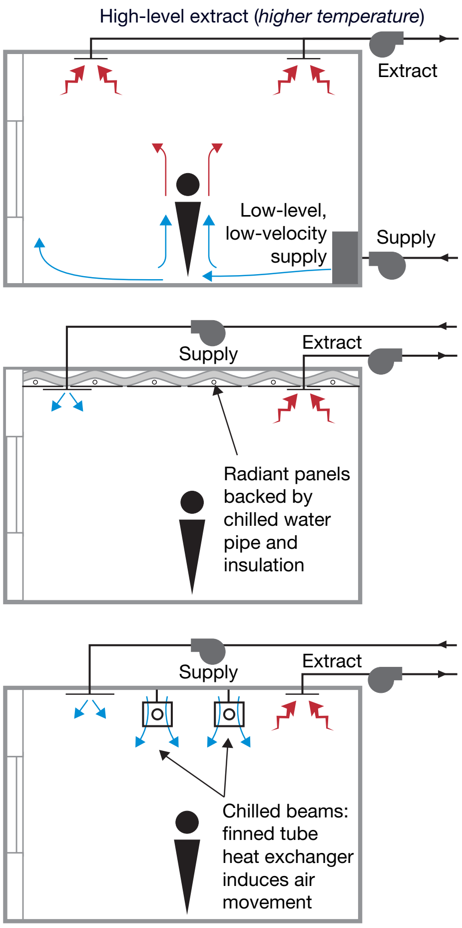


Figure 14 Alternative cooling systems

a) **Displacement ventilation**
Only cools areas where there is heat gain

b) **Chilled ceiling**
Cools partly by radiant effect

c) **Static chilled beams**

MECHANICAL COOLING STRATEGIES

- With chilled ceilings (see figure 14b), chilled water is passed through piping that is attached to the back of conducting ceiling panels. Alternatively, pipes may be embedded into precast ceiling slabs. Cooling is via radiation and convection. The radiation effect allows the thermal comfort of the occupants to be attained at higher room air temperatures than with air-only systems.
- With static chilled beams (see figure 14c), the room air is induced over finned chilled water pipes inside a casing using natural buoyancy effects.
- Active chilled beams add supply air from an air-handling unit via the beam; the extra air movement increases the cooling effect.

As with any ceiling-mounted system, these devices need to be carefully integrated into the ceiling design along with the lighting and partitioning layout, etc.

Static chilled ceilings and chilled beams should not be used in spaces where a lot of moisture is generated as this could result in condensation problems. They also can not deal alone with very high cooling loads, such as those in computer equipment rooms.

5.1.6 Night cooling

An established technique, night cooling passes the cool night air through the building to remove heat that has accumulated in the building fabric during the day. The building fabric is cooled and so it can absorb more heat the following day, and temperature increases are reduced. The movement of cool night air may be natural or fan-assisted.

The 'free' cooling of the building reduces energy consumption for mechanical cooling and ventilation is reduced, leading to cost savings.

5.1.7 Refrigeration machines

A heat pump of some description will generally be used to mechanically cool a building. Typically, the heat pump used will be based on the vapour compression cycle, like most domestic refrigerators. This involves transferring heat into and out of a fluid, called a refrigerant, which is circulated within the heat pump. Some refrigerants have considerable environmental impact in terms of global warming potential (GWP) and ozone depletion potential (ODP) if they are released to the atmosphere:

- CFCs – high GWP and high ODP; production phased out in 1995
- HCFCs – high GWP, low ODP; production will be progressively cut to a total phase out in 2015
- HFCs – substitute for HCFCs; they have zero ODP but still high GWP.

For more details see BRE Information Paper 16/95, 'The safety and environmental requirements of new refrigerants'[11].

Alternative refrigerants can be used, such as propane, isobutane and ammonia, etc, however their application is limited by other considerations. To avoid replacement later, stipulate that you require a refrigerant that conforms to anticipated Regulations throughout the life of the system.

Absorption machines use a chemical process to produce a cooling effect but have lower efficiencies than vapour compression machines. However, where waste or cheap heat is available (eg from combined heat and power), then absorption refrigeration systems may be a cost-efficient alternative. Also, as they use mainly thermal energy rather than electricity, their CO_2 emissions may be lower.

5.2 LOW-ENERGY COOLING SYSTEMS

As an alternative to mechanical cooling, low-energy cooling methods are available which make use of the cooling effects of:

- ground water
- evaporative cooling
- the ground itself
- outdoor air.

5.2.1 Ground water cooling

Underground water may be used as a cooling source (see figure 15a). Below a certain depth, water is often available at a temperature which is almost constant all year round.

Low temperature water is extracted from a well and pumped to the surface where it passes through a heat exchanger which separates ground water from

MECHANICAL COOLING STRATEGIES

system water to avoid any cross contamination. The system water can be used as chilled water. Having picked up heat from the system water, the ground water is returned via a separate 'soakaway' well.

Only certain sites have suitable ground water sources at convenient depths, so careful investigation is required.

Biological activity and maintenance may present some difficulties, but if these can be overcome cooling can be provided year-round for just the pumping energy. Approval must be sought from the local water authority for abstraction.

5.2.2 Evaporative cooling

When water evaporates, it takes heat from its surroundings, thus providing cooling.

Direct cooling is where water is sprayed directly into the supply airstream. Alternatively, it can be sprayed into the exhaust air, which is then passed through an air-to-air heat exchanger to cool the supply air. This avoids changing the humidity of the supply air.

Indirect cooling is where the airstream is separated from the evaporating water by a heat exchanger. It can take the form of a cooling tower, from which water can be used as chilled water (see figure 15b). Indirect evaporative cooling is preferred as it avoids the possible micro-biological contamination of the supply or exhaust air.

The drawback with evaporative cooling is that performance is lowest when it is needed the most, that is on hot, humid summer days when the outdoor air is least able to absorb the evaporated moisture. Although this system is not particularly effective in peak conditions, it can be used to offset mechanical cooling for most of the year.

5.2.3 Earth-to-air/water heat exchangers

If the earth temperature is cool enough it is possible to use it to cool a building. Air or water may be channelled underground and cooled in subterranean heat exchangers before being delivered to the building (see figure 15c).

Heat transfer depends upon soil type, moisture content and ground water movement. Cleaning and maintaining a subterranean air heat exchanger has to be considered, especially to control microbiological contaminants.

5.2.4 Outdoor air ('free') cooling

In many buildings the major heat gains occur all year round, so that there is a need for cooling when the outside air is cool. 'Free' cooling uses this outside air to reduce inside temperatures without having to run chiller plant. It can be brought in directly if the system uses air distribution, or water sent through the cooling tower can be used instead of water from the chillers. Since plant such as fans is still needed to distribute free cooling around the building, the calculation of whether the result has a lower cost in use must include all consequential energy, maintenance and other cost implications.

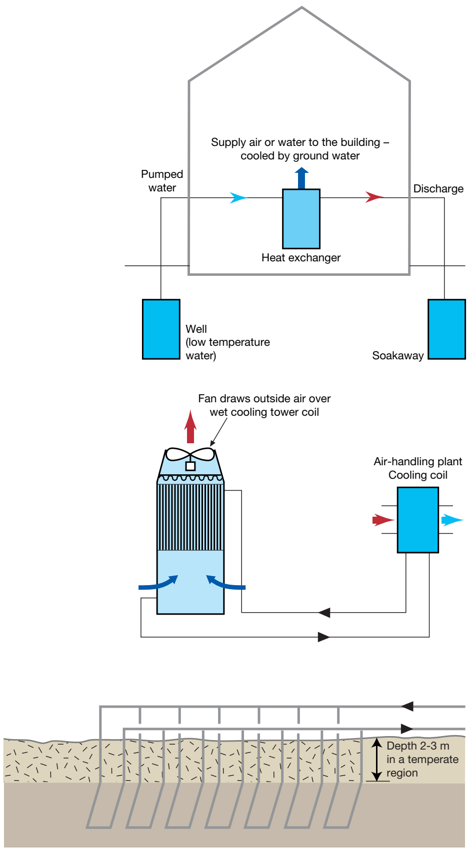


Figure 15 Low-energy cooling systems

a) Ground water cooling

b) Evaporative indirect cooling
Cooling tower connected to an air-to-air heat exchanger

c) Earth-to-water heat exchanger

6 THE BRIEF

The brief should be described comprehensively and coherently. It should include both the user and the client requirements, including foreseeable changes.

The activities within the building will dictate:

- the amount of individual occupant control
- whether temperature and humidity need to be controlled to a tight tolerance
- the level of internal heat gain from office equipment, lighting, etc
- the amount of ventilation air that needs to be provided (derived from occupancy density)
- zoning requirements
- flexibility in spatial layout changes.

The brief should be clear about the client's environmental policy (eg which BREEAM rating is required) and should detail energy targets to which the building should perform. Life-cycle costing should be considered. This takes account of estimations of the annual recurring costs for energy, maintenance, replacement and repair, as well as capital costs and interest charges.

More details of the business benefits of adopting an energy-efficient, environmentally smart solution are given in GPG 285[2].

6.1 CLIENT'S BRIEFING CHECKLIST

This checklist sets out the issues that need to be covered in the client's brief for the design team. As a general condition, it is important that the brief requires that the ventilation and the cooling systems should:

- be easily maintainable
- provide the required internal conditions
- operate with minimal detriment to the external environment
- have a reasonable operating cost.

Comparison between options should be on the basis of life-cycle cost and not simple payback or initial capital costs.

Table 2 Client's briefing checklist

Environmental policy	Determine your policy on the external environment, for example limiting emissions of CO_2, BREEAM rating, etc. If refrigerants have to be used then environmentally acceptable refrigerants must be considered, together with precautions against emission to the atmosphere. Anticipate pending regulatory changes on acceptable refrigerants.
Basic parameters	Location of the site. Is the building in the city centre, suburban or rural? (Any obvious sources of external air or noise pollution?) Building thermal characteristics; seek standards as high as can be justified by life-cycle cost analysis: ■ high levels of insulation ■ airtight construction ■ modest glazed areas and shading to minimise heat gains from the sun ■ internal heavy construction to absorb heat gains and delay their effect. Assess the safety and security issues which may need specific requirements, eg restrictions on ventilation openings at night, fire and smoke control issues, maintenance requirements, etc. Take into account any foreseen future alterations to the building and any changes to the building function. With the design team, establish an energy target for the building. For typical buildings, published yardsticks will be useful (see EEBPp ECONs, page 32). Seek advice on whether centralised or unitary systems would be most appropriate to the occupant requirements.
Occupants	Assess the current and future activities of the occupiers – how will this affect internal heat gain, small power, lighting, computer, communications and other such process loads? Take into account any foreseen future changes in the occupancy density and patterns of use, but be wary of oversizing plant 'just in case'. Plant running at part load is often less efficient.

THE BRIEF

Occupants *(continued)*	What are the current small power loads ? Are they likely to increase in the future? Assess the expectations of the occupants in terms of internal environmental conditions and availability of individual control.
Servicing strategies	What are the options for the building plan shape? Narrow plan (<15 m)will accommodate natural ventilation and mixed-mode more readily. If it has to be deep plan (>15 m), and indoor summertime temperature peak not critical, consider ventilation stacks, thermal flues and wind scoops to extend the application of natural ventilation. Prompt the design team to consider night cooling of the building structure. This will provide a source of cooling for the following day. If mechanical ventilation is considered, the use of exhaust air heat recovery should be explored by the design team – balancing energy and associated CO_2 emissions of space-heating savings against the extra fan energy used. If mechanical ventilation is considered, aim to set low specific fan power in the design criteria (preferably <1 $kW/m^3/s$ and certainly no greater than 2 $kW/m^3/s$). Prompt the design team to check if there are any useable natural sources of cooling available to the site – ground or surface water, ground coupled coils, etc. If cooling is a necessity, prompt the design team to consider an energy-efficient approach to the distribution systems; eg heating and cooling transported by water rather than air, displacement ventilation, chilled ceilings, chilled beams. If mechanical cooling is used, prompt the design team to consider energy-efficient enhancements, such as free cooling, control of the chiller compressor speed, resetting the condenser water temperature, etc.
Controls	Identify if different building areas require different environmental conditions, and which have different occupancy periods. Are the occupants to be given local controls? Do the environmental conditions really need to be tightly controlled or can they be allowed to vary?
Maintenance and management issues	Assess whether the complexity of a system is appropriate to the requirements – the best maxim is to keep it as simple as possible to meet user needs. Ensure that the operators can understand how the system should be operated for energy-efficient performance. Require that the commissioning phase includes briefing for the future operators of the system, and that the operation and maintenance manuals are written so that future operators can understand the system without needing to be briefed verbally. Ensure there is adequate space and access to carry out regular maintenance of plant, cleaning of ventilation air paths, etc. Ensure that there is a programme of planned preventative maintenance. Determine whether the maintenance work is to be contracted out or provided by in-house staff. Ensure that the maintainers of the system are adequately trained for the job, and do not override energy efficiency plant to make their jobs simpler.
Capital and operating cost constraints	Ask for cost estimates for a range of different system options. Assess the life-cycle costs of the equipment.

APPENDIX – COMPARISON OF STRATEGIES

	PASSIVE COOLING SYSTEMS					
	Approximate cooling load in W/m² 25			30		
	Natural ventilation			**Mechanical ventilation** ***Mixed-mode (mechanical and natural ventilation)***		
SYSTEMS	Openable windows	Motorised vent openings + night cooling	Stack ventilation + night cooling	Extract ventilation + night cooling	Supply and extract mechanical ventilation + night cooling	Hollow core slabs + night cooling
Dry bulb temperatures	Control will be lost during peak summertime conditions.	Night cooling will improve summertime temperatures – reducing peak temperature by approximately 2-3ºC compared with peak temperatures with natural ventilation.		More predictable performance from night cooling, under all conditions.		Greater accessible mass, so night cooling should perform better than simple mechanical ventilation system.
Humidity	No control.			No control.	Winter humidification is possible, to avoid risk of static electricity shocks.	
Air movement	Occupants near the perimeter have reasonable control – single-sided ventilation can be used up to a maximum depth of two-and-a-half times the floor-to-ceiling height. Cross ventilation provides adequate air movement up to a limit of a depth of approximately five times the floor-to-ceiling height.		Air movement will be improved during peak summer (still) conditions because of stack driving forces.	Needs to be applied on a mixed-mode basis – mechanical ventilation for winter and night cooling, natural ventilation for summertime.		Reasonable air movement can be achieved by the mechanical ventilation throughout the year.
Odour level control	Good dilution rates achievable at the perimeter. Wintertime ventilation needs to be considered with care. Trickle ventilation is an option but avoid the creation of cold draughts by location of the vent at high level, or preheat the air.		Better year-round performance than simple natural ventilation.	Good year-round performance with wintertime minimum fresh air rates guaranteed. Fresh air rates are set according to odour source.		
Air cleanliness	Absence of control over source can be problematic for buildings adjacent to busy roads, industrial sites which create dust and dirt, or rural sites which may suffer from high pollen levels.		No control. Stack pressures too low for conventional air filtration.	No control, unless the make-up air to a room is filtered.	Any filtration of a normal standard is achievable – the price for higher air cleanliness is capital cost and increased fan energy.	

APPENDIX – COMPARISON OF STRATEGIES

MECHANICAL COOLING SYSTEMS

40	70	100	>100 W/m^2		
Displacement ventilation	**Static cooling systems**		**Unitary air-conditioning**	**All air systems**	**Air and water systems**
Floor supply system (office application)	Chilled ceilings with ventilation air	Chilled beams with ventilation air	VRF, part-centralised (Versatemp), split systems	Floor supply (fully mixing within room), VAV systems	Fan coil units, induction units
Reasonable control throughout the year, temperature gradients will exist through the occupied space – design to a limit of 3ºC between ankle and head.	Reasonable year-round control, radiant panel – self-compensating in that output increases as room temperature rises.	Reasonable year-round control.	Reasonable year-round control – terminal units normally use on/off.	High quality control possible. Scope for free air cooling.	High quality control possible. Scope for free cooling of water via cooling tower.
Year-round humidity control is possible, but dehumidification coupled with high supply temperature may require reheat which consumes more energy.	Separate fresh air system can provide dehumidification and, if necessary, humidification. Ventilation air volume flow would be set to carry summer dehumidification load, using a separate cooling source.		Some dehumidification on the room units. Year-round control possible if fresh air system used in conjunction with these systems.	Year-round humidity control can be achieved.	
Reasonable air movement; however displacement air patterns can be broken up if the building has high infiltration rates.	Reasonable air movement, less lively than all air systems.		Reasonable air movement.	Good air movement can be engineered by careful location of terminal units.	
Good year-round performance with wintertime minimum fresh air rates guaranteed.	Good year-round control provided by the ventilation air system.		If separate fresh air system used, good-quality odour control is achievable.	Good year-round control.	
Ventilation air can be arranged to have normal levels of filtration.	Ventilation air can be arranged to have normal levels of filtration.		Filtration on room units is normally coarse. If separate fresh air used good air filtration is achievable.	Good filtration standards achievable.	

APPENDIX – COMPARISON OF STRATEGIES

	PASSIVE COOLING SYSTEMS					
	Approximate cooling load in W/m^2		25	30		
	Natural ventilation			**Mechanical ventilation** ***Mixed-mode (mechanical and natural ventilation)***		
SYSTEMS	Openable windows	Motorised vent openings + night cooling	Stack ventilation + night cooling	Extract ventilation + night cooling	Supply and extract mechanical ventilation + night cooling	Hollow core slabs + night cooling
Flexibility in spatial planning	Spatial layout changes can be accommodated where single-sided ventilation serves less than 4 m depth. Cross-flow ventilation arrangements incompatible with cellular offices if they occupy a whole façade on each floor.		Stacks can be arranged to serve deep cellular spaces, but spatial layout changes are restricted.	Reasonable flexibility in spatial layout changes, however care must be taken when introducing partitions which block air paths. May also be uncomfortable with high occupancy densities (eg one person/2 m^2 in meeting rooms).		
Space requirements for plant and distribution systems (all areas are expressed as percentage of treated floor area for a typical office building)	No plant space required for ventilation or cooling.		Stacks may occupy part of gross floor area, but use of stairwells or atria to generate stack effect will minimise impact on occupied areas.	Space requirement for air-handling plant approximately 1%.	Space requirement for air-handling units and risers approximately 3-5%. For buildings with higher ventilation loads, eg retail, plant will be larger and space requirements greater.	
HVAC energy indicators (based on a building with good thermal characteristics which is well managed and maintained – see notional building page 30)	Same area as notional building but narrow plan. Simplest of systems yields the low energy consumption. Good practice office buildings: ■ space heating 72 kWh/m^2 ■ fans and pumps 3 kWh/m^2			Using mechanical ventilation supply and extract with exhaust air heat recovery: ■ space heating 60 kWh/m^2 ■ fans and pumps 8 kWh/m^2 Low energy but fan energy can be significant. Particularly if control of the operational hours is sloppy, fan energy can be several times the figure given above.		
HVAC-related CO_2 emissions in notional building (page 30) Based on: ■ electricity – 0.46 kg/kWh ■ gas – 0.19 kg/kWh	Same area as notional building but narrow plan: ■ heating 13.7 kg/m^2 ■ fans and pumps 1.4 kg/m^2 ■ **HVAC total 15.1 kg/m^2**			■ Space heating 11.4 kg/m^2 ■ Fans and pumps 3.7 kg/m^2 ■ **HVAC total 15.1 kg/m^2**		

APPENDIX – COMPARISON OF STRATEGIES

<table>
<tr><th colspan="6">MECHANICAL COOLING SYSTEMS</th></tr>
<tr><th>40</th><th>70</th><th>100</th><th colspan="3">>100 W/m²</th></tr>
<tr><th>Displacement ventilation</th><th colspan="2">Static cooling systems</th><th>Unitary air-conditioning</th><th>All air systems</th><th>Air and water systems</th></tr>
<tr><td>Floor supply system (office application)</td><td>Chilled ceilings with ventilation air</td><td>Chilled beams with ventilation air</td><td>VRF, part-centralised (Versatemp), split systems</td><td>Floor supply (fully mixing within room), VAV systems</td><td>Fan coil units, induction units</td></tr>
<tr><td>Floor supply systems offer good flexibility and good multi-room control. May need to reposition inlets where partitions are introduced.</td><td>Chilled ceilings need design attention to accommodate likely spatial layout changes – eg likely partition lines, zoning of the chilled water feeds and provision for changing control zones.</td><td>Chilled beams are slightly less restricted than ceilings but care is still needed on chilled water zones and control zones.</td><td>Flexibility very good.</td><td colspan="2">Flexibility good if the system layout is matched to space planning module.</td></tr>
<tr><td>Space requirement for chillers, heat rejection, air-handling plant and risers approximately 4-6%.</td><td colspan="2">Space requirement for chillers, heat rejection, air-handling plant and risers approximately 3-6%.</td><td>Perimeter room units alone may require 1% without centralised fresh air plant. If fresh air plant is used space requirement will be 1.5-2.5%.</td><td>All-air systems will require approx 4-8%. Horizontal duct distribution may also require increased floor-to-floor heights.</td><td>Air and water systems will require typically 3-6%, 1% of which is for perimeter units. Horizontal duct distribution needs to be considered, although fresh air ducts will be smaller than on all air systems.</td></tr>
<tr><td>With maximum heat gain of 40 W/m²:
■ space heating 52 kWh/m²
■ fans and pumps 15 kWh/m²
■ cooling 5 kWh/m² with exhaust air heat recovery</td><td colspan="2">With maximum heat gain of 70 W/m²:
■ space heating 50 kWh/m²
■ fans and pumps 11 kWh/m²
■ cooling 23 kWh/m²</td><td>With a maximum heat gain of 95 W/m²:
■ heating 39 kWh/m²
■ chillers 22 kWh/m²
■ fans and pumps 18 kWh/m²
(Assumes direct electric heating and ventilation air at 1 air change per hour).</td><td colspan="2">With a maximum heat gain of 95 W/m²:
■ heating 59 kWh/m²
■ chillers 11 kWh/m²
■ fans and pumps 20 kWh/m²

The above example is a well-run system, from ECON 19; more typically:
■ heating 222 kWh/m²
■ chillers 33 kWh/m²
■ fans and pumps 61 kWh/m²</td></tr>
<tr><td>■ Heating 9.9 kg/m²
■ Fans and pumps 6.9 kg/m²
■ Chillers 2.3 kg/m²
■ HVAC total 19.1 kg/m²</td><td colspan="2">With chilled ceilings and primary air:
■ heating 9.5 kg/m²
■ fans and pumps 5 kg/m²
■ chillers 10.6 kg/m²
■ HVAC total 25.1 kg/m²</td><td>■ Heating 7.4 kg/m²
■ Fans and pumps 8.3 kg/m²
■ Chillers 10.1 kg/m²
■ HVAC total 25.8 kg/m²</td><td colspan="2">In a good practice building:
■ heating 11.2 kg/m²
■ fans and pumps 9.2 kg/m²
■ chillers 5 kg/m²
■ HVAC total 25.4 kg/m²

More typically:
■ heating 42.2 kg/m²
■ chillers 15.2 kg/m²
■ fans and pumps 28 kg/m²
■ HVAC total 85.4 kg/m²</td></tr>
</table>

APPENDIX – COMPARISON OF STRATEGIES

	PASSIVE COOLING SYSTEMS					
	Approximate cooling load in W/m² 25			30		
	Natural ventilation			**Mechanical ventilation** ***Mixed-mode (mechanical and natural ventilation)***		
SYSTEMS	Openable windows	Motorised vent openings + night cooling	Stack ventilation + night cooling	Extract ventilation + night cooling	Supply and extract mechanical ventilation + night cooling	Hollow core slabs + night cooling
Capital costs £/m² of treated floor area All costs based on 1997 prices and rates	HVAC systems typically £35/m² to £40/m². Case study 1A school – natural ventilation using stacks: ■ HVAC £56/m² ■ total building £656/m² Case study 1B university building – natural ventilation with stacks + night cooling ■ HVAC £115/m² ■ total building £855/m²			HVAC systems typically £40/m² to £80/m². Case study 2A office + light industrial spaces – natural ventilation and mechanical extract + night cooling ■ HVAC £83/m² ■ total building £997/m² Case study 2B offices natural ventilation (cross-flow) + mechanical ventilation ■ HVAC £117/m² ■ total building £886/m² Case study 2C offices – natural ventilation using stacks with mechanical ventilation + night cooling ■ HVAC £90/m² ■ total building £926/m² Case study 2D university building (offices) natural and mechanical ventilation with hollow core slabs + night cooling ■ HVAC £74/m² ■ total building £820/m²		
Maintenance costs – HVAC systems	Typically £0.80/m² to £1.40/m². If motorised openings are used £3/m² to £5/m².			Typically £1.80/m² to £2.40/m².		
References	1A John Cabot CTC. Building Services, May 1994 1B De Montford University. NPCS 102			2A Atlantis Building. The Architects' Journal, 2 March 1994 2B Inland Revenue, East Kilbride. The Architects' Journal, April 1995 2C Scottish Office, Leith. The Architects' Journal, 7 December 1995 2D Elizabeth Fry Building. NPCS 106		

APPENDIX – COMPARISON OF STRATEGIES

MECHANICAL COOLING SYSTEMS

40	70	100	>100 W/m^2		
Displacement ventilation	**Static cooling systems**		**Unitary air-conditioning**	**All air systems**	**Air and water systems**
Floor supply system (office application)	Chilled ceilings with ventilation air	Chilled beams with ventilation air	VRF, part-centralised (Versatemp), split systems	Floor supply (fully mixing within room), VAV systems	Fan coil units, induction units
Typically HVAC services £120/m^2 to £140/m^2. Case study 3A museum ■ HVAC £128/m^2 ■ total building £912/m^2 Case study 3B college ■ HVAC £170/m^2 ■ total building £382/m^2 Case study 3C office ■ HVAC £141/m^2 ■ total building £1057/m^2	Typically HVAC costs £125/m^2 to £150/m^2. Case study 4A office – chilled beam and displacement ventilation ■ HVAC £156/m^2 ■ total building £917/m^2 Case study 4B offices – chilled beams + displacement ventilation ■ HVAC £158/m^2 ■ total building £987/m^2		Typically HVAC costs £115/m^2 to £130/m^2.	Typically HVAC costs £160/m^2 to £250/m^2.	Typically HVAC costs £140/m^2 to £200/m^2.
Typically £6/m^2 to £10/m^2.	Typically £5/m^2 to £8/m^2.		Typically £10/m^2 to £20/m^2.	Typically £7.5/m^2 to £13/m^2.	Typically £9/m^2 to £15/m^2.
3A Techniquest Centre. Building Services, April 1996 3B British School. Building Services, January 1992 3C Britannic Assurance. Building Services, November 1996	4A Barclaycard HQ Building Services, April 1997 4B Coop Retail Building Services, August 1996				

APPENDIX – COMPARISON OF STRATEGIES

THE NOTIONAL BUILDING

A six-storey rectangular office building has a length of 46 m, a width of 18 m and a floor-to-ceiling height of 3 m; the building long axis points east-west.

Total treated floor area is approximately 5000 m^2.
The lighting load is assumed to be 15 W/m^2. The small power load is assumed to be 15 W/m^2.

Occupancy of one person per 10 m^2, the latent and sensible occupancy loads were taken for light work with the internal temperature maintained between 22ºC and 24ºC.

Glazing has a U-value of 3.3 W/m^2K and covers 50% of each façade seen from the outside.

Solar gain data, as well as outdoor air temperature and enthalpy were taken for Kew, London.

Occupancy is assumed to be between the hours of 8am and 6pm, Monday to Friday.

Fresh air is supplied at a minimum of 8 l/s/person.

Where appropriate, the boiler efficiency is taken to be 0.75, hot and chilled water distribution efficiencies both 0.90.

Fan efficiency is taken as 0.75, the combined fan motor and drive efficiency is 0.95.

REFERENCES

[1] ***Energy Efficiency Best Practice programme.*** Good Practice Guide 291 'Ventilation and cooling option appraisal – a designer's guide'. DETR, London, 2000

[2] ***Energy Efficiency Best Practice programme.*** Good Practice Guide 285 'What will energy efficiency do for your business?'. DETR, London, 2000

[3] ***Energy Efficiency Best Practice programme.*** Good Practice Guide 165 'Financial aspects of energy management in buildings'. DETR, London, 1995

[4] ***Energy Efficiency Best Practice programme.*** General Information Report 30 'A performance specification for the Energy Efficient Office of the Future'. DETR, London, 1995

[5] ***Chartered Institution of Building Services Engineers.*** CIBSE Guide A 'Environmental design'. CIBSE, London, 1999

[6] ***Building Research Establishment.*** BRE Report (BR)350 'BREEAM 98 for offices'. BRE, Garston, 1998

[7] ***Building Research Establishment.*** BREEAM Version 2/91 'An environmental assessment for new superstores and supermarkets'. BRE, Garston, 1991

[8] ***Building Research Establishment.*** BREEAM/New Industrial Units. Version 5/93 'An environmental assessment for new industrial, warehousing and non-food retail units'. BRE, Garston, 1993

[9] ***Building Research Establishment.*** BRE Report (BR)278 'Environmental Standard: homes for a greener world'. BRE, Garston, 1995

[10] ***Energy Efficiency Best Practice programme.*** NatVent Guide 'Natural ventilation for offices'. DETR, London, 1999

[11] ***Building Research Establishment.*** Information Paper (IP)16/95 'The safety and environmental requirements of new refrigerants'. BRE, Garston, 1995

FURTHER READING

ENERGY EFFICIENCY BEST PRACTICE PROGRAMME DOCUMENTS

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

Energy Consumption Guides

18 Energy efficiency in industrial buildings and sites
19 Energy use in offices
36 Energy efficiency in hotels – a guide for owners and managers
51 Energy efficiency in sports and recreation buildings: a guide for owners and energy managers
54 Energy efficiency in further and higher education – cost-effective low energy buildings
72 Energy consumption in hospitals
75 Energy use in Ministry of Defence establishments

Introduction to Energy Efficiency in Buildings

2 Catering establishments
3 Shops and stores
4 Health care buildings
6 Offices
8 Museums, galleries, libraries and churches
9 Hotels
10 Post offices, building societies, banks and agencies
11 Entertainment buildings
12 Prisons, emergency buildings and courts
13 Factories and warehouses

General Information Report

59 Natural ventilation: good practice in the UK

Good Practice Case Study

308 Naturally comfortable offices – a refurbishment project

Good Practice Guides

118 Managing energy use. Minimising running costs of office equipment and related air-conditioning
134 Energy efficiency for shopping centres
144 Energy efficiency in sports and recreation buildings: technology overview. A Guide for owners and managers
201 Energy efficient refurbishment of retail buildings
205 Energy efficient refurbishment of hotels and guesthouses – a guide for proprietors and managers
219 Energy efficiency in swimming pools – for centre managers and operators
258 Looking for a new investment angle? A developer's guide to environmentally smart buildings
276 Managing for a better environment. Minimising running costs and impact of office equipment
288 Is poor energy performance in the office hitting your bottom line?

New Practice Case Studies

102 The Queens Building, De Montfort University – feedback for designers and clients
106 The Elizabeth Fry Building, University of East Anglia – feedback for designers and clients
114 The Inland Revenue Headquarters – feedback for designers and clients

NatVent® Guide

Natural ventilation for offices

This Guide is based on material drafted by Ove Arup and Partners under contract to BRECSU for the Energy Efficiency Best Practice programme.

The Government's Energy Efficiency Best Practice programme provides impartial, authoritative information on energy efficiency techniques and technologies in industry and buildings. This information is disseminated through publications, videos and software, together with seminars, workshops and other events. Publications within the Best Practice programme are shown opposite.

Visit the website at **www.energy-efficiency.gov.uk**

For further information on:

Buildings-related projects contact:
Enquiries Bureau
BRECSU
BRE
Garston, Watford WD25 9XX
Tel 01923 664258
Fax 01923 664787
E-mail brecsuenq@bre.co.uk

Industrial projects contact:
Energy Efficiency Enquiries Bureau
ETSU
Harwell, Oxfordshire
OX11 0RA
Tel 01235 436747
Fax 01235 433066
E-mail etsuenq@aeat.co.uk

Energy Consumption Guides: compare energy use in specific processes, operations, plant and building types.

Good Practice: promotes proven energy-efficient techniques through Guides and Case Studies.

New Practice: monitors first commercial applications of new energy efficiency measures.

Future Practice: reports on joint R&D ventures into new energy efficiency measures.

General Information: describes concepts and approaches yet to be fully established as good practice.

Fuel Efficiency Booklets: give detailed information on specific technologies and techniques.

Introduction to Energy Efficiency: helps new energy managers understand the use and costs of heating, lighting, etc.