Key questions when designing a new building and how it will be cooled include:

1. Can I design this building to stay comfortable without mechanical cooling? (e.g. through passive design and passive cooling techniques)

2. If not, can I limit or contain the heat gains to a level such that only localised, low-energy cooling systems are required?

3. If this is not possible, how can a full building system be designed to minimise its energy use as far as possible?

1.0 Introduction

Buildings need to provide comfortable environments for their users, including by regulating temperature, humidity, odours and contaminants in the air. Average air temperatures in southern England are projected to rise by as much as 4 °C by 2080 due to climate change (UK Climate Impacts Programme, www.ukcip.org.uk/). In central London the ‘urban heat island effect’ is likely to exacerbate the intensity of heat waves. This will increase the need for, as well as the challenges involved in, designing buildings that maintain comfortable internal temperatures. Without design or retrofit for future higher temperatures, it is predicted that many buildings will suffer from overheating by the 2020s. Moreover, increasing energy costs and climate change mitigation programmes, such as the Carbon Reduction Commitment, mean that buildings which use large amounts of energy to heat or cool will incur increasing financial penalties for their users.

Low energy cooling systems are therefore important to:

- Increase satisfaction and comfort of users
- Reduce greenhouse gas emissions
- Reduce energy costs (and associated penalties linked to climate change legislation)
- Avoid the risk of future overheating.

A common approach to cooling buildings in the past has been to rely on air conditioning. However, use of mechanical cooling, and particularly use of air conditioning, can be energy intensive with high associated levels of carbon dioxide (CO₂) emissions and significant heat output (which can in turn exacerbate the overheating of dense urban areas). Energy use associated with air-conditioning (refrigeration, fans, pumps etc) in UK offices is estimated to account for almost a third of the energy expended in an air-conditioned office building. An analysis of future cooling demand in London indicated that, if left unchecked, the growth in active cooling systems in London could lead to a doubling of CO₂ emissions from this source by 2030¹.

This note explores what alternative low energy cooling solutions are available that can meet requirements for providing a safe and comfortable internal environment while minimizing energy use and CO₂ emissions.

It is critical that building services, including cooling, form an integral part of the overall building design to ensure they operate efficiently. A specialist building services engineer should therefore be involved at an early stage in the design process. Comfort parameters for winter and summer should be set with the client and engineers; where possible the benefits of a flexible approach to temperature limits should be emphasised. For example, Buro Happold, Feilden Clegg Bradley and Max Fordham developed a brief for the BRE New Environmental Office which set a range of acceptable summertime temperatures: above 25°C for up to five per cent of the working year and above 28°C for one per cent of the working year. Building users who have a more active influence on their environment tend to adapt better to more extreme conditions, hence the design conditions for naturally ventilated buildings with user control are often less rigid than for those that are fully air-conditioned.

Figure 1: BRE’s Environmental Office, Garston. Image courtesy of James Fisher, BRE
2.0 Cooling hierarchy

When designing a building the following cooling hierarchy should be followed to ensure energy use associated with cooling is minimised:

1. **Passive design** to minimise unwanted heat gain and manage heat – for example by using building orientation, shading, a well insulated and air tight building envelope, high levels of thermal mass and energy efficient lighting and equipment.

2. **Passive/natural cooling** – using outside air to ventilate and cool a building without the use of a powered system, for example by maximising cross ventilation (single aspect developments are generally discouraged), passive stack ventilation, night-time cooling and/or ground coupled passive cooling.

3. **Mixed mode cooling** with local mechanical ventilation/cooling provided where required to supplement the above measures using (in order of preference):
   - Low energy mechanical cooling (e.g. fan-powered ventilation with/without evaporative cooling or ground coupled cooling)
   - Air conditioning (not a preferred approach as these systems are energy intensive)

4. **Full building mechanical ventilation/cooling system** using (in order of preference):
   - Low energy mechanical cooling
   - Air conditioning

The use of thermal modelling to understand the performance of a proposed new building design under future temperature scenarios, for example using CIBSE future weather data which incorporates current climate change models for 2020 and 2050 (see www.cibse.org/index.cfm?go=publications.view&item=406), would be encouraged to ensure that any proposed new building is designed to mitigate the risk of overheating.

Each of the steps in the cooling hierarchy is expanded upon in the sections below, including details of low energy mechanical cooling systems. The importance of designing ‘coolth’ delivery systems to maximize efficiency is also highlighted.
3.0 Passive design

Passive design is about controlling unwanted summer heat gain (40W/m² is generally regarded as excessive heat gain) by controlling i) direct solar gains; ii) heat transfer and infiltration; iii) internal heat generation. Examples of key ways to address each of these areas are provided below.

Controlling direct solar gains:

- Orientation of building – orientated as far as possible to reduce excessive solar gain and facilitate natural ventilation.

- Solar control – all means of controlling solar gain should be considered including the location, size, design and type of window opening and glazing; use of solar shading devices (e.g. brise soleil); and use of green roofs and vegetation for shading and evaporative cooling. Solar shading should be designed to avoid substantially reducing daylighting or generating a need for year round electric lighting (leading to increased energy consumption and heat generation).

Controlling heat transfer and infiltration:

- Insulation/u-values should be maximised as far as possible and materials should be selected to prevent penetration of heat.

- A tight building envelope is important to minimise uncontrolled air infiltration – attention to detailing and sealing is critical; air permeability rates should be minimised as far as practicable.

- Use high thermal mass – exposed building fabric such as masonry or concrete, or new ‘phase change materials’, can be used as ‘thermal batteries’, absorbing heat gains during the day when the building is occupied and storing it for an extended period, thereby helping to stabilise daytime temperatures. This heat can then be dissipated at night (to reset the system), usually using ventilation. Ground coupled systems can also be used to make use of thermal storage in the ground.

- Green roofs – have been shown to have a significant effect in cooling buildings, particularly areas directly under them. Where use of a green roof is not practicable, consider use of a roof with a high albedo (reflective) surface to minimise the heat absorbed by the roof and high thermal insulation to prevent any heat absorbed being transferred into the building.

\(^1\)Common points of infiltration include gaps around the perimeter of doors and windows, the areas where door and window frames meet a wall and the junctions of walls, ceilings and floors.
Controlling internal heat production:
• Use efficient lighting (e.g. LED lighting) and appliances/equipment
• Locate equipment that generates large amounts of heat where gains can be removed quickly from the space before they become cooling loads.

Managing heat within a building:
• Use exposed internal thermal mass and high ceilings.

Green roofs and cooling
Poorly protected and insulated roofs can lead to substantial overheating of spaces beneath them. This can lead to the need for increased air-conditioning. A green roof not only acts as an insulation barrier, but the combination of plant processes (photosynthesis and evapotranspiration) and soil processes (evapotranspiration) reduce the amount of solar energy absorbed by the roof membrane, thus leading to cooler temperatures beneath the surface.

Research by Nottingham Trent University has found that on a typical day with a temperature of 18.4°C the temperature beneath the membrane of a normal roof was 32.0°C, while the temperature beneath the membrane of a green roof was 17.1°C. A study conducted in Chicago, USA, recently estimated that building energy savings to the value of $100,000,000 could be saved each year if all roofs were greened, as the need for air conditioning would be reduced.

For more information on green roofs see Islington’s Green roofs and walls good practice guide – www.islington.gov.uk/greenplanningguidance
4.0 Cooling systems – general issues

After passive design measures have been designed-in, some form of ventilation/cooling may still be required. Cooling systems come in many types but whether passive, mechanical or a combination, they need to enable local control and meet health, comfort and cooling needs. Use of intelligent building control systems - that use a combination of monitoring sensors and computerised control to monitor and control energy consuming equipment such as heating, ventilation, cooling and lighting - would be encouraged where appropriate.

A crucial factor for energy efficiency is defining the optimum ventilation rate – over supply of fresh air will lead to excessive energy consumption while an inadequate amount of fresh air will result in a rapid decline in internal air quality. BS5925:1991 suggests a minimum ventilation rate of eight litres of fresh air per second per person.

Contingency planning is important when designing cooling systems. Flexibility for future changes of uses should be designed in where possible, for example by providing spare cooling capacity, or retaining space for extra plant and service routes. All cooling systems should be designed to maximise operational lifespan and minimise maintenance requirements.

If a ventilation/cooling system is required in a building, then in accordance with the cooling hierarchy, passive cooling should be considered first.

Figure 4: Brise soleil on Islington Council’s offices.
5.0 Passive cooling

‘Passive’, or ‘natural’, ventilation is the ventilation of a building with outside air without the use of a fan or other powered mechanical system. Passive cooling systems are typically associated with the design of new buildings but there are also cases where existing buildings have been adapted using the same principles. Buildings that are passively ventilated generally use less energy than those with mechanical based ventilation and air conditioning. They also tend to have lower running costs and capital and maintenance costs. Costs for passive ventilation systems can be balanced against the capital and operating savings achieved by minimising the size of heating, ventilating and air conditioning (HVAC) systems required.

Passive systems may be inappropriate in some circumstances. High levels of noise or pollutants and other external environmental conditions which may limit or preclude use of natural ventilation need to be identified at an early stage and minimised where possible. If windows need to be kept shut to keep out noise, fumes or dirt, localized mechanical ventilation may be required. In situations where high levels of cooling/ventilation are required, passive ventilation may not be sufficient to maintain the target temperatures required nor bring in the required volume of fresh air (although it may still be useful as a supplement to more active cooling systems).

Key types of passive cooling include cross ventilation, passive stack ventilation, passive nighttime cooling and earth cooling, as described below.

5.1 Cross ventilation

Simple passive cooling can be achieved with operable windows when the spaces to ventilate are small and the architecture permits. For example, cross ventilation can be obtained by opening windows on both sides of a room/building, causing airflow across the space (assuming there is a relatively clear path for the air to flow across). Positive pressure on the windward and/or a vacuum on the lee side of a building causes air movement across the room/building. Ideally the windows on the windward side of the building are opened less than the windows on the lee side in order to give an optimal airflow with as little draught as possible. Alternatively, side fins can be built onto the outside of a building to create positive pressure on one side and negative pressure on the other, enhancing cross flow ventilation. Cross ventilation can be effective to a depth of up to 5 times the room height.
An obvious downside of this form of cooling is that it is dependent on the presence of wind for good ventilation. Windows can also cause localised discomfort due to draughts and cold radiation in winter, or solar gain in summer. However, occupants of naturally ventilated buildings with openable windows are generally willing to accept a wider range of room temperatures than occupants of sealed air-conditioned buildings. A well designed and positioned window should allow adequate ventilation on warm, breezy days without causing uncomfortable draughts. Trickle vents in window frames can be used to maintain a low ventilation rate in winter, avoiding cold draughts and excessive heat loss caused by opening windows.

Windows and other openings (e.g. vents alongside windows) can be opened mechanically using powered actuators and controlled as part of a building management system with links to wind/temperature sensors to optimise energy efficiency and comfort.

With larger buildings more complex passive cooling systems will be required. Popular systems include passive stack ventilation, night-time passive cooling of thermal mass and earth/labyrinth cooling of supply air – these approaches are considered further below.

### 5.2 Passive stack ventilation

Passive cooling can be achieved by utilising the ‘stack effect’ and often also the driving force of the wind (or the related ‘venturi effect’, where air passing over the top of a duct causes a drop in pressure that sucks the air upwards out of the duct). Such systems bring fresh air into a building (e.g. through low level vents on the windward side of a building) and expel stale warm air from high level openings (often at the top of a ‘chimney’ or atrium), exploiting the fact that as warm air rises it decreases the air pressure within a space, thus drawing in more cool air as the room air is displaced.
Temperature difference is the driving force of the stack effect, therefore stack ventilation requires the air outside to be cooler than the internal air – the greater the thermal difference and the height of the structure, the greater the buoyancy force. ‘Thermal chimneys’, wind cowls, or wind turbine vents can be used to reinforce the effect of hot air rising (using the sun’s heat or the wind) to induce increased air movement for cooling purposes.

**Case study 1: Whole building passive stack ventilation system, Queens Building, De Montfort University**

The Queens Building at De Montfort University provides an example of large building using a holistic passive stack ventilation system with proven performance in use.

The building is highly insulated with large areas of exposed thermal mass, a shallow plan and generous ceiling heights to promote natural ventilation and daylighting. Fresh air enters the building through low level openings/grills, is warmed, rises up and is exhausted through vertical shafts and ridge vents. Intake air can be heated by finned tubes behind the openings to avoid cold draughts. A simple fan is installed in one stack in each auditorium to aid ventilation when necessary (e.g. on warm, still days). Motorised dampers on the stacks and inlets maintain internal air temperatures and CO\(_2\) levels. In the summer outside air is used to cool the building’s thermal mass during the night down to 17ºC.
In winter when cooling is not required, vents in passive ventilation systems can be closed (fully or partially). In mechanical or mixed mode ventilation systems (see below), heat recovery systems can be used to extract heat from evacuated warm moist air to pre-warm cool, dryer incoming outside air. However, heat recovery is generally incompatible with wholly passive ventilation systems due to the high airflow resistances associated with the high efficiency heat exchangers.

Passive stack ventilation systems use very little energy but care must be taken to ensure the occupants' comfort in all seasons, taking into account predicted increases in summer temperatures with climate change. Internal temperature modeling will be useful to identify any need for supplementary localised mechanical cooling, but this should be designed out where possible. The careful design of openings to ensure that wind direction does not cause reverse flow will also be important (e.g. by using rotating air scoops).

As air leakage through the building fabric is minimised (to comply with tightening building regulations and sustainable building standards), the need for a managed air flow through a building to ensure a safe, comfortable internal atmosphere is maintained is increased. The ability of a given passive ventilation system to generate the required exchange of air therefore needs to be carefully evaluated. The German Passivhaus standard, which promotes extremely well insulated and sealed buildings, requires use of low energy mechanical ventilation (with heat recovery) to maintain the quality of indoor air.

Case study 2:
Simple passive stack ventilation, John Thompson Architects, Islington

Simple passive ventilation systems can be retrofitted to existing buildings to reduce energy use. John Thompson Architects have carried out a green retrofit on their office building in Clerkenwell to ensure it is adapted to future changes in climate. The installation of simple manually controlled openers on windows, doors and an existing stairwell roof vent has improved the building's natural ventilation. Fresh air is drawn in through windows, cooling the offices, as hot air rises up the stairwell (making use of the stack effect) and is exhausted through an opened roof hatch. Other features include: solar panels mounted above south facing windows to provide additional shade, whilst generating renewable energy; reflective paint on the roof to reflect heat away from the building; and use of innovative ‘phase change’ materials within office roofs, which absorb heat during the day and release it at night.
5.3 Night-time cooling/’purging’

As mentioned above, where a building makes use of high thermal mass (e.g. masonry, concrete or new ‘phase change materials’) to absorb heat and thereby moderate internal daytime temperatures, night-time ‘purging’ can be used to dissipate the heat stored in the building fabric. This is critical where thermal mass is high to ensure that temperatures can be reduced sufficiently for the next day’s use (opening windows during the day will have little effect on the temperatures in such buildings, since they store a lot of heat and therefore a lagged response and fast, close control of temperature is not possible). Purging can be achieved passively, or by using mechanical fans to drive air flow (although the latter obviously involves energy consumption), through ventilation of floor voids or the floors themselves using louvred vents. Stack ventilation is particularly effective for night time passive cooling as this is when there is the greatest differential between internal and external temperatures.

Case study 3:
Night-time passive cooling, The Courtyard, Bill Reed Architecture

Given concerns about the reliability of complex cooling solutions and their effective operation by building users, this modern office development adopts a simple, low maintenance, low energy solution to meet its cooling requirements. The office combines a considerable thermal mass with ventilated louvres backed by doors into the building that are simply opened at the beginning of the summer to let the cool night air in, and closed in the autumn. The result, according to an occupier, is “the only green building we occupy that actually works”.

Thermal mass is provided at no additional material cost by using engineering brick seconds throughout, with precast concrete floor planks, creating a reassuringly solid-feeling building. However there is a time cost: the rate at which brick courses can be laid is reduced as the bricks’ weight displaces the mortar and the exposed floors have a significant drying period. Where an internal finish to the brickwork is needed, the wall is rendered rather than plastered but optimally, brickwork is left exposed and simply painted, giving the added benefit of increasing net lettable floor area.

The ventilated louvres allow cool night air to flow through the building, passing over the exposed heavy construction and pre-cooling it for the following day. Modelling of air temperatures indicated that with reasonable assumptions about heat gains and provided the louvres were open overnight the temperature would be at 25°C or below for 95% of the occupied period over a year. This meets the British Council for Offices recommendation for naturally ventilated buildings. Security concerns were overcome by using heavy duty extruded aluminium slats and a stainless steel mesh keeps out birds and insects.

Source: Bill Reed, Reedspace Ltd; www.reedspace.com/pdfs/aecasestudy.pdf
5.4 Ground coupled passive air cooling

Ground coupled passive air cooling, also sometimes referred to as earth or labyrinth cooling (two different passive cooling systems), involves using pipes/earth tubes’ buried in the ground or labyrinthine concrete passageways beneath a building to passively cool fresh air, which is then supplied to a building’s interior (and potentially moved through the building using a passive stack system). Because the earth is at a constant temperature of around 10-12°C at greater than 5m depth, passing air underground provides free pre-warming of air in winter and pre-cooling during the summer, thereby reducing the need for active heating and cooling plant. In summer air can be cooled from 28°C down to around 17°C, while in winter air can be warmed from below zero to around 5°C.

Design considerations include ensuring pipework is designed to prevent bacterial growth and to enable thermal conductivity to the ground; and considering the quality of intake air and the possible need for air filters. Since the surrounding ground will be heated as summertime air passes through the system, the rate at which the cooling output of the system is reduced during continuous operation should also be considered. Excavation costs need to be taken into account, but these will be reduced where installation forms part of a new build project.

Case study 4: Ancient system of passive ground coupled cooling in Iran

Use of ground coupled passive air cooling is not a new technology. In Persia a system incorporating ‘windcatchers’ has been used for centuries (see image of the windcatcher of Dowlat-abad on p.7). One variant of these devices involves drawing in external air underground through a tunnel carrying water. The cooler subterranean soil temperature, the cool night air that has aggregated in these low chambers and the evaporative cooling effect of the water all combine to reduce the temperature of the air stream before it enters the building through a low level opening. The effect of wind and/or the passive stack effect (see section 5.2 above) on the wind tower suck the cool air up through the building and out from a high level opening, driving the system without the need for any mechanical augmentation.

6.0 Low energy mechanical cooling

Passive ventilation alone may not be sufficient to cool a building to the required temperature. For example, in a building with high thermal mass using passive night cooling, the internal daytime temperature may be lower than the external temperature, therefore introducing the air needed for control of humidity, odour and contaminants could warm the building. Where passive cooling and passive design is not sufficient to meet users’ needs, supplementary mechanical ventilation/cooling can be provided. There are a range of ‘mixed mode’ solutions that can provide intermediate options, as summarised in the box below.

**Mixed mode cooling options**

- Complementary designs function with both systems operating together, concurrently or in changeover mode. An example is to rely on natural ventilation/cooling by opening windows in cooler months while using mechanical cooling in hotter months.

- Zoning designs work by allowing for passive and mechanical systems to be used in different zoned parts of a building. For example, keeping the bulk of a building naturally ventilated while grouping all significant heat producing equipment (e.g. computer server equipment) into a space with the appropriate mechanical cooling, and/or where the waste heat can be used for another purpose.

- Contingency designs incorporate both types of system so that each can be used as a back-up to the other.

Mixed mode systems have some key advantages over passive ventilation systems – they can enable tighter control of internal temperatures, independent of weather conditions; the risk of cold drafts from openings is reduced; and a greater flexibility in building layout is allowed since this no longer has to be dictated by natural ventilation requirements.

The control system is crucial to a successful mixed mode system. It needs to be capable of continually monitoring internal and external environments (e.g. temperature, wind speed and direction) and using predictive algorithms to calculate how much natural and mechanical ventilation is required and adjust the appropriate openings and fan settings accordingly.

The most energy efficient form of mechanical cooling is mechanical ventilation using fans to circulate air (assuming the air is sufficiently cool). Fan-powered ventilation should not be confused with air conditioning which is a much more complex and energy intensive operation involving the cooling of air using a refrigeration system (see section 7.0).
6.1 Fan-powered ventilation

The simplest form of fan is a table or ceiling fan which circulates air within a room, but these are not technically classed as ventilation as they do not bring in fresh external air. Simple mechanical ventilation systems are mechanical extract systems for a kitchen or bathroom to control odours or humidity. Whole building ventilation systems use air handling units (AHU) typically containing separate supply and extract fans to replace indoor air with outside air.

All mechanical ventilation systems should include heat recovery to ensure that heat from evacuated warm air can be re-used to pre-warm incoming supply air when needed, thereby avoiding the need to use excessive energy to heat ventilated rooms on cold days. Some heat recovery systems are now able to store recovered heat in ‘thermal batteries’ so that if the heating of incoming air is not required instantaneously the heat can be saved until it is needed. In airtight properties (<5m³/hr/m² at 50Pa), mechanical ventilation heat recovery systems can be highly energy efficient since almost all ventilation air passes through the heat exchanger.

Where more comprehensive fan-powered systems are required they should be designed to maximise their efficiency, for example using low specific fan power and efficient inverter driven fans. The Energy Saving Trust state that:

- continuous mechanical extract ventilation systems should have a specific fan power (SFP) of 0.6W/l/s or less;
- whole building mechanical ventilation systems with heat recovery should have a SFP of 1.0W/l/s or less and a heat recovery efficiency of 85% or better.

The sizing of systems should be closely matched to demand. Where possible the fan power should be supplied from onsite renewables. A case study of an innovative low energy whole-building mechanical cooling system is provided below.

Mechanical ventilation can also be used to facilitate night time purging of thermal mass, as referred to in the section on passive cooling above.

Drawbacks of mechanical ventilation systems include: fans can consume a significant amount of energy (a reason for introducing air-conditioning was because refrigeration could cost less, and use less energy, than pushing large quantities of air around a building) and can warm the air stream by up to 2°C; occupants may have less control over internal temperatures/air quality in comparison to natural ventilation and may be less tolerant of high internal temperatures as a result; AHUs and ductwork occupy valuable space and require maintenance; and as with natural ventilation, the cooling capacity of the system is limited by external conditions.
This 4000m² office development (RIO Architects, King Shaw Associates and Scott Wilson) achieved BREEAM Excellent with a score of 87.55% (in 2007), the highest rating given to any building. Key to the building’s success is its high level of thermal mass and innovative ventilation system. The thermal mass is provided by the concrete structure (40% recycled content). It is externally insulated to high levels (0.15W/m²°C) and exposed internally to stabilise internal temperatures. A fully passive ventilation system was rejected because of high occupancy, IT loads and noise and air pollution concerns. Instead, a fan-assisted core slab ventilation system was adopted (a similar system to that proved at the Elizabeth Fry building, UEA), using precast concrete floor planks with hollow cores that are linked up to create an air circulation network. This system allows additional contact between the fresh circulated air and the interior of the floor planks, ensuring that the majority of the thermal mass of the concrete (rather than just its surface) can be used to warm/cool supply air before it is distributed to rooms.

In winter, heat recovery air-handling units collect internal heat gains (high insulation levels mean internal gains can provide the majority of useful heat) and store them in the floor slabs to heat the incoming air. In summer, the building uses cool night air and, when necessary, mechanical refrigeration from a CCHP plant to pre-cool the building core and reduce peak cooling demand. The cooling potential of the system in the UK climate can be 40 W/m² (using no active cooling) to 50 W/m² (with active cooling) at a room temperature of 26°C (a top temperature of 26°C was agreed rather than BCO’s standard of 22°C).

Calculations by King Shaw Associates indicate the new building, to accommodate up to 420 people, will produce just 22kg of CO₂/m²/yr and will emit 80% less carbon than a typical air conditioned office, equating to a projected financial saving of £14/m²/yr.

Photo credit: Doug King, King Shaw Associates. Sources:
www.iesve.com/content/mediaassets/pdf/IES%20Consulting%20Case%20Study%20-%20Thorpe%20Park.PDF
6.2 Fan-powered ventilation and evaporative cooling

Where cooling of the incoming fan-driven air supply is required, use of evaporative cooling could be considered. Evaporative cooling is a process that uses the effect of evaporation as a natural heat sink. Evaporative cooling can be direct or indirect; passive or hybrid.

Direct evaporative cooling increases the water content of the cooled air because supply air is brought into contact with evaporated water. For example outside air can be brought into a building via a ‘cooling tower’ where it is passed over an evaporating coil, turning the ambient air into cool dense air that then sinks into the building, displacing warmer stale air in the process. Since high evaporation rates might increase relative humidity and create discomfort, these systems need to be carefully designed to ensure the internal air does not become excessively humid. Systems should also be designed to prevent or control the growth of Legionella, including species that can cause legionnaire’s disease.

In indirect evaporative cooling, evaporation occurs inside a heat exchanger and the water content of the cooled air remains unchanged, therefore there are no problems with increasing humidity.

Limitations of such systems include it being difficult to provide fast/close temperature control and/or humidity control, the need for a larger plant than a conventional system with similar cooling loads (with higher energy requirements), and the need to consider water consumption and cost.

Figure 8: Termite mounds use evaporative cooling in addition to thermal mass and convection currents to maintain a constant internal temperature. Image source: Manfred Schweda, thisfabtrek.com.
6.3 Ground coupled cooling

An alternative low energy mechanical cooling system is ground coupled cooling. Passive ground coupled cooling has already been covered in section 5.4 above. Earth tubes or a labyrinth system can also form part of a mechanical cooling system by combining either technology with a fan-powered ventilation system to move the pre-cooled/pre-warmed air around a building (see case studies below).

Another form of ground coupled cooling involves mechanically circulating a liquid (e.g. water) through a pipe in the ground buried at an appropriate depth in order to cool the liquid to the low sub-soil temperature. Warm room air, or a refrigerant used to cool a building, can be passed through one side of a heat exchanger and the heat transferred to the liquid in the pipe (which is also passed through the heat exchanger) removing the heat from the building. The heated liquid is then circulated back through the pipe under the ground and the heat is transferred into the ground, the liquid is cooled and the process starts again.

Ground source cooling thus relies on using the large cold mass of the earth as a heat sink to provide the necessary cooling. The methods of accessing the heat sink capacity of the earth using liquid can be categorised into two groups – closed loop and open loop systems.

Closed loop systems circulate a fixed volume of liquid around a pipe circuit in thermal contact with the earth – the circuit can be horizontal (in trenches), or vertical, in a borehole. Open loop systems use cold water pumped directly from a borehole, watercourse or water body (e.g. a canal; water at depth will remain cold relative to air temperature). Doing this requires an Abstraction Licence from the Environment Agency. Disposal of the slightly warmed water from the heat exchanger must also be considered - it can be pumped back into the source, but warm water is considered to be a pollutant so a Discharge Consent would be required. For more information on using canal water for cooling see British Waterways' guidance at www.britishwaterways.co.uk/be-part-of-it/business-opportunities/cooling-and-heating-buildings

Both open and closed loop systems consume electricity to pump liquid around the loop – where possible this should be supplied from onsite renewables.

*Systems are now being tested that use 'interseasonal heat transfer' to store excess summer time heat in an insulated thermal store under ground, enabling the heat to be re-used in winter to improve heat pump performance for heating. Achieving thermal balance over the year is important in such systems to ensure the ground temperature is maintained.*
Design considerations include ensuring pipework is designed to prevent bacterial growth and to enable thermal conductivity to the ground. Since the surrounding ground is heated as liquid passes through the system, the rate at which the cooling output of the system is reduced during continuous operation should also be considered. Excavation costs need to be taken into account, which can prohibit the provision of spare capacity, but where the system is installed as part of a new build project, these costs will be reduced. The performance of ground heat pumps will be enhanced where there is movement of ground water across the loop.

Case study 6: Earth tubes at Highbury Grove School

The new development of Islington’s Highbury Grove School site was shortlisted for an award recognising its environmentally sustainable credentials in the Building Schools for the Future (BSF) programme. Many aspects of the Highbury Grove and Samuel Rhodes development make it a contender for the award. Low energy consumption and low carbon energy production are at the core of the site’s design which will reduce CO₂ emissions by twenty per cent through the use of onsite renewable technology.

Besides combined heat and power, green roofs and solar shading, the design also incorporates ‘earth tubes’. Site constraints led to a large proportion of the school being mechanically ventilated, so earth tubes, in this case giant underground concrete ducts, were used to exchange heat and cool with the ground, helping to reduce the amount of heating the school needs and minimising or eliminating the need for mechanical cooling in classrooms.
Case study 7:
Labyrinth cooling at the Planet Earth Gallery

Atelier Ten environmental engineers completed their first labyrinth cooling system at the Planet Earth Gallery for the Earth Centre in Doncaster. The design removed the need for air conditioning for the 6,500m² exhibition space. The labyrinth was formed as an integral part of the raft foundations in the structure beneath the gallery floor. It consisted of a series of concrete passageways, which were also used to distribute electrical and exhibition services. The performance of the labyrinth was simulated using thermal modelling allowing optimisation of materials, geometry, and surface roughness.

Air is moved through the labyrinth at very low speed so the energy required to drive the circulation fans was minimised. A 500m² photovoltaic array covering the main entrance generated sufficient electrical power to run the ventilation system, making the system effectively carbon neutral.

Image: © Atelier Ten
7.0 Air conditioning systems

Air conditioning (AC) systems are defined here as systems using the refrigeration cycle to provide comfort cooling of buildings. These systems are distinct from ventilation systems in that they physically remove heat from indoor air.

AC systems generally use the vapour compression cycle as the source of cooling and tend to include all electrically driven systems and components. Consequently they can consume significant amounts of energy and generate substantial carbon emissions. In addition, many systems still use HCFC refrigerants, which contribute to depletion of the Earth’s ozone layer.

Absorption refrigerators are a popular alternative to compressor refrigerators where electricity is unreliable or expensive or where surplus heat is available. For example, where a building has a combined heat and power plant generating waste heat, this may be used to drive chilling equipment to supply cooling air to a building. Given the current carbon intensity of grid electricity these systems are likely to be more carbon efficient than AC systems using the vapour compression cycle, however this could change as the grid is decarbonised.

AC systems (vapour compression and absorption refrigerators) are considered here as a last resort as they tend to be energy intensive with high associated CO₂ emissions relative to the passive and low energy cooling systems outlined above. There is also evidence to suggest that AC systems can be detrimental to occupant health and wellbeing. Before considering AC systems the cooling hierarchy should be worked through and all passive cooling, passive design and lower energy cooling technologies tested for feasibility and incorporated where practicable. Use of AC systems is generally only likely to be justifiable on a localised basis when close temperature/humidity control is required, or where internal gains are very high (e.g. in a computer server room, where passive solutions – including locating the room away from the south elevation of a building – are insufficient).

Where use of AC systems is unavoidable, they should be used in combination with low-energy technologies where possible and the energy (and carbon) consumption of the system should be maximised.

It is also important to recognise that AC systems have to dump heat somewhere. This heat has the potential to cause problems for the occupants of other buildings, people in public spaces and the environment in general. The design of AC systems should therefore consider carefully where waste heat will be “dumped” to ensure that it will not cause problems for others or the environment in general, as well as exacerbating the urban heat island effect.

Ways to minimise the energy consumption of air conditioning systems

1. Use low specific fan power and efficient inverter driven fans in air handling
2. Use advanced responsive controls
3. Supply power from onsite renewables where possible
4. Design in ‘free cooling’ wherever possible to reduce the demand for AC and hence reduce energy consumption (e.g. by using cool outside air in winter)
8.0 Delivery systems for maximum efficiency

Where cool air or water needs to be delivered to specific spaces from its source, careful thought should be given to the design of the delivery system since this can have a significant impact on the efficiency of a cooling system. Delivery systems which provide the required cooling performance using higher air or chilled water temperatures (e.g. chilled water at 14-16°C rather than 6-8°C) tend to offer substantially greater energy saving potential by making low energy cooling solutions and free cooling options more viable (e.g. cooling towers and ground coupled cooling) and enabling a higher coefficient of performance. They should therefore be used where possible.

Higher temperature delivery systems include water cooled slabs, chilled beams/ceilings and displacement ventilation.

**Water cooled floor slabs** – cooling is delivered by radiation from concrete floor slabs incorporating an embedded pipe circulating chilled water at around 14-20°C. These systems can be used to supplement a night cooling ventilation strategy (see Innovate building case study above) or to provide additional cooling during peak times.

**Chilled beams and ceilings** – chilled beams are long rectangular sections containing a tube through which chilled water is circulated at around 16°C. Chilled ceilings consist of a chilled water pipe arranged in a serpentine coil and fixed to a metallic panel. Chilled beams use convective air movement to provide cooling to a room, while chilled ceilings transfer cooling mainly by radiation.
Displacement ventilation – this involves supplying cooled air to a space via low level wall or floor outlets. The cool air tends to remain at low level until it comes into contact with a local heat source such as a person or IT equipment. It is then warmed and rises to the top of the space where it is extracted via a high level extract system. Displacement ventilation thus relies on buoyancy-driven air movement within a space rather than forced air movement as with a conventional mechanical ventilation system. This approach ensures that the cooling capacity is supplied directly to those parts of a room where it is most needed; moreover the temperature of the extract air at the ceiling can be allowed to rise above comfortable levels as it is above the occupied zone. The result is that to provide the same cooling capacity the supply air does not need to be cooled as much as it would be in a conventional system (e.g. 18–20°C as opposed to 15–18°C). This approach requires rooms with high ceilings and spaces where there will be limited disturbance to the air (e.g. no constant movement of individuals) and it has limited cooling capacity, although displacement systems are often combined with other cooling systems such as chilled ceilings.
9.0 Key information sources and acknowledgements


CIBSE Design Compass. A free online tool to assist professionals involved in building design to incorporate weather/climate related information into a clearly defined framework - http://www.cibsedesigncompass.org.uk/

The review comments provided on a draft of this document by Prof. Doug King of King Shaw Associates are gratefully acknowledged.


Note: These guidance notes are advisory only and not Supplementary Planning Documents. However following their advice will help developments satisfy various policies contained within the London Plan and meet wider sustainability objectives.
Low energy cooling
Good Practice Guide

A range of passive and active technologies can be used to provide low energy cooling of buildings instead of relying on energy intensive air conditioning. This note sets out a cooling hierarchy, providing good practice guidance on the steps that should be taken and the types of low energy cooling technology that are suitable in Islington, alongside a range of examples of where such techniques have been successfully incorporated within developments.

This Good Practice Guide is part of a set of notes providing information on sustainable design for planners, developers and interested residents or businesses. The set includes guidance on the following:

- Good Practice Guide 1: Green Roofs and Walls
- Good Practice Guide 2: Sustainable Drainage Systems
- Good Practice Guide 3: Climate Change Adaptation
- Good Practice Guide 4: Biodiversity in the Built Environment