CURRENT THINKING ON...

FREE COOLING AND LOW-ENERGY SYSTEMS

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Free cooling is a general term used to describe the use of naturally available cooling sources to provide cooling to building air conditioning systems.

Various systems exist and new free cooling technologies are being implemented continually across the world as part of the search for more carbon-friendly building design solutions. The implementation of the new part L building regulations will require a closer look at free cooling to allow designers and operators to meet the required carbon targets.

Table 1. Ventilation rates
prior to non smoking regulations in uk

Level of smoking	Proportion of occupants who smoke %	Fresh air supply rate litre/sec/person
No smoking	0%	8
Some smoking	25%	16
Heavy smoking	45%	24
Very heavy smoking	75%	36

Large scope for ventilation and air conditioning savings due to reduced ventilation requirement since building designs prior to no smoking regulations

Table 2. Heat recovery options
mainly used on heating cycle, can be used on cooling cycle with good control over system

	Efficiency (%)	Pressure drop (Pa)	Cross leakage %	Adjacent ducts needed	Cost	
Run around coil	40 - 50	200 - 500	0	No	Low	Needs control and pump
Plate heat exchanger	40 - 70	250 - 500	0 - 5	Yes	Low	No pump or power required low maintenance
Thermal wheel	60 - 85	200 - 500	1 - 10	Yes	High	High maintenance if air is not clean
Run Around Coil with Heat pump	100 - 140	200 - 500	0	No	High	Electrical power required Needs control

The no smoking in public buildings laws in the UK have reduced the required ventilation rates in buildings from 36 air changes per hour to eight. This means that there is now even greater scope to meet the ventilation and cooling requirements of public buildings with free cooling and natural ventilation alone **(see Table 1).**

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The average annual air temperature in all regions of the UK is under 100C. In summer the average is under 160C. Under normal conditions there is enough free cooling in the air to maintain normal building space temperatures at 230C for most of the time. The water temperature and ground temperatures are almost continually below 100C and as such the scope for free cooling using water or ground source is high in all situations.

Free cooling using air is available when the outside air enthalpy (enthalpy = total of sensible heat + latent heat in the air) is less than the indoor air enthalpy. The external air with lower enthalpy is transferred to the building either directly or indirectly using ventilation systems or heat exchangers. Refrigeration systems can be used to upgrade free cooling but this requires an energy input and is considered a low energy technology.

Free cooling is generally available in four basic types.

- using ambient air to provide free cooling directly;
- using water sprayed directly into the airstream (indirect and direct humidification with adiabatic cooling);
- using river or lake water to provide free cooling to the air via a heat exchanger;
- using the ground as a cooling source to the air directly or indirectly.

Free cooling can be supplied to simple mixed air ventilation systems by fitting automatically controlled dampers on the outside air intake, exhaust air outlet and the recirculation ductwork controlled by enthalpy or temperature controls with appropriate sensors located in the ductwork. The system effectively increases the fresh air to the building if the outside air is colder than the required air temperature to assist in cooling. The hotter exhaust air is not recycled back into the building but exhausted.

The dampers are automatically modulated to control at the set point by increasing the amount of outside air brought into the building and reducing the re-circulated air. In this way refrigerated cooling is minimised especially at night and in winter. During the day in summer when the ambient is above the required building space temperature the fresh air damper will close and the recirculation damper will open to recycle the cooler treated air from the building.

Older systems simply control on temperature, modern automatic systems control on enthalpy as humidity and moisture sensors and controls are now relatively low cost and reliable.

Sensible cooling may also be achieved in some cases by the use of direct spray humidifiers. These spray water into the air steam to cool the air. The water temperature is lower than the air temperature and so the air temperature drops as it absorbs the water until the dew point is reached at which point the air is saturated and can no longer absorb water. The humidifier is controlled by an automatic system to maintain

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Fig 1. Heat exchanger + Indirect humidification

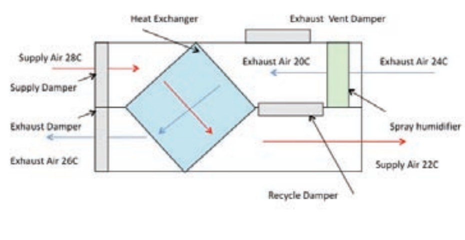


Fig 2. Free cooling - Water cooling

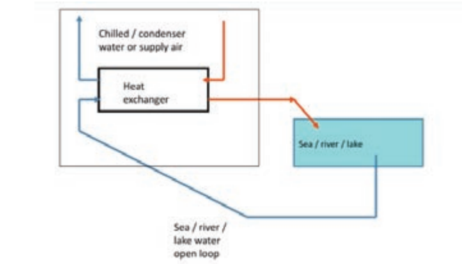
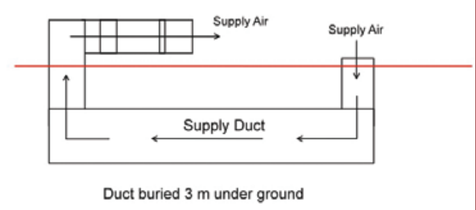


Fig 3. Free cooling - Ground source ducting



the required humidity for comfort conditions and to avoid the dew point being reached.

Spray humidifiers provide additional free cooling in addition to providing humidification with no reduction in total enthalpy this is called adiabatic cooling (constant enthalpy cooling).

These humidification systems were the norm until the 1990s, but the health and safety and cost issues associated with Legionnaires' Disease have made these systems less attractive. Steam humidification is now normally used but these increase the cooling load rather than reduce it.

Direct spray humidification may now be an acceptable option in some cases where the water is known to be free from Legionella. Matrix type evaporative spray humidifiers are now available which give the benefits of free cooling and can be safe from legionella risks if properly installed and operated.

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100 per cent fresh air systems are normally fitted with heat recovery or free cooling heat exchangers. There are a number of options but the most popular is a cross over matrix heat exchanger fitted in the supply duct with the exhaust air passing across the other side of the matrix heat exchanger block. Others include thermal wheels and run around coils. This will supply free cooling when the outside temperature is warmer than the exhaust temperature by recovering the cooling from the exhaust air. Additional free cooling can be supplied by an evaporative indirect humidifier in the exhaust air duct prior to the heat exchanger. Free cooling is available when the external ambient temperature exceeds the temperature in the exhaust duct after the evaporative humidifier has reduced the temperature by adiabatic cooling. Sensible heat is removed from the supply air by the lower temperature exhaust air. The supply air moisture content is not increased as the water spray is on the extract side of the ducting.

When the external ambient temperature is lower than the temperature after the evaporative humidifier then free cooling is supplied directly from the free air provided from the outside air. Intelligent automatic controls enable these systems to operate seamlessly producing saving of over 60 per cent of energy compared to the normal mixed flow refrigerated cooling systems installed throughout the UK. As the water is not sprayed into the supply stream and there are no 'legionella' implications **(see Fig.1).**

Water-cooled systems provide free cooling from the sea, underground wells, rivers or lakes. The cool water is pumped in a loop through a heat exchanger to cool either:

- the air supply to the building, directly via a water to air heat exchanger;
- the supply air indirectly via a cold water loop and secondary water to air heat exchanger.

The system can be used to cool any air supply system either by fitting a pre-cooling heat exchanger at the supply to an air handling unit or by fitting water to air heat exchangers directly at each ducted entry to the passive ventilation system in the building. If a suitable water source is available then this is normally the most cost effective free cooling solution. Aquifers or underground wells are dug below many buildings in Europe to provide free cooling. The only power required for these systems is to drive a circulating pump and power the controls. **(see Fig.2).**

The ground can be used as a cooling source to cool the air directly or indirectly. If the ventilation air is supplied to the building via a specially designed duct which is buried some 2-3m underground, the ground will absorb heat from the air as it passes along the duct reducing its temperature and sensible heat.

The ground temperature never rises above 100C. With an outside temperature of 300C the air could easily be cooled to 230C if the duct were long enough and the heat transfer sufficient to remove the heat from the air before supplying the building. This could be enough to prevent the need for refrigeration. At the very least a large reduction in the refrigeration load would be made.

Ground source cooling can also be used with passive ventilation systems with the air supply connected directly to the building supply ducts. This is an attractive option for buildings with plenty of ground space available. It is very low technology with no specialist parts or heat exchangers and low maintenance. Flow velocities and associated noise can be very low if multiple ducting is used to supply individual areas of the building. This is particularly suitable for displacement ventilated buildings with the cooling supplied from below the floor **(see fig.3 and fig.7)**.

Another method is to fit a water to air heat exchanger in the air handling unit inlet duct and feed the primary side of the heat exchanger with water pumped through specially designed heat exchange pipe work which is laid underground. The water is continually pumped round the system similar to the sea, river and lake heat exchangers. The heat exchanger pipe work takes up less space and requires less energy than the corresponding simple duct system in Fig.3. It does however require an additional pre-heater battery to be fitted on the supply to the building. This could also be used in conjunction with passive ventilation with the heat exchanger fitted at building ventilation ducts. **(see fig.4).**

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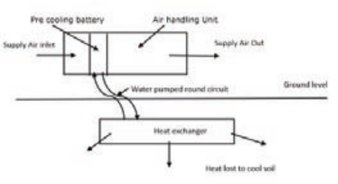
Free cooling is associated with a number of low energy cooling and passive cooling techniques many of which will be applied when free cooling is used. This especially applies to new buildings.

These include:

- cooling recovery systems such as heat exchangers, thermal wheels, and run around coils. These are all integral to free cooling and the range of equipment available is growing as technology progresses. The use of standard fixed cross over heat exchangers is now being replaced by more efficient heat pump and thermal wheel systems as the demand for lower carbon utilisation increases. **See table 2** for relative recovery system performance.

Dehumidification systems can use desiccant dryers. To optimise free cooling using spray water systems, the air should be as dry as possible prior to cooling. In order to achieve this various air drying techniques are possible but the most common are desiccant driers, either fixed systems with alternate drying cylinders or a desiccant wheel. The fixed system is where the air is passed through a chamber filled with a desiccant such as silica gell or pearlite and the desiccant absorbs the moisture. When the desiccant in the chamber is

Fig 4. Free cooling using ground heat source heat exchanger



saturated the airflow is redirected into another desiccant chamber and the first is regenerated by either heating the desiccant or passing dry air or nitrogen over it.

It is common where the humidity is high such as in equatorial countries to use thermal wheels and desiccant wheels to dry the air and recover the sensible heat. The wheel surface is made up of a honeycomb matrix which allows air to pass through it and has a desiccant distributed throughout the wheel matrix. As the wheel rotates between the supply air and the exhaust air the moisture is removed from the supply air and moved to the relatively dry exhaust air. These systems are expensive but are becoming more popular even in moderate climates. They should not be used in dirty or contaminated environments, only where the air is relatively clean.

Passive ventilation systems will become standard in future buildings. Forced ventilation systems will only be used if natural ventilation is not possible. A mixture of forced and natural will be used in some cases. Numerous buildings have already been designed using passive systems and the research has found these to be successful. Passive ventilation and free cooling if designed into the building will enable most buildings to operate without the need for refrigeration systems.

Three main types of passive ventilation are used:

- traditional natural ventilation using windows;
- thermal stack systems;
- wind driven systems;
- displacement ventilation.

Natural ventilation using normal windows which are opened by the user as required. These are applicable in single or two storey buildings. Automatic window opening and closing can be part of an overall building strategy.

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In thermal stack systems heat is used to drive the ventilation. As hot air rises it is vented at the top of the building and draws cold air into the bottom of the building, automatic damper systems with some partial forced ventilation can be used as part of an overall building heating and ventilation strategy **(see Fig.5)**.

Wind-driven systems are used where the building is designed to make use of the prevailing winds to drive the ventilation system such as a wind scoop where there is a rotating air inlet at the top of the building which follows the wind to scoop the air into the building and so create a positive pressure to drive the ventilation through the floors **(see Fig.6)**.

Displacement ventilation is where the cold air is fed into the bottom of the rooms and is exhausted at the top. The air flow is slow moving and the room height needs to be at least 4m from floor to ceiling to allow the natural ventilation to work **(see Fig.7).**

Buildings are generally unoccupied at night and the ambient temperature normally drops at night. If the building is designed with passive cooling then there is scope to increase the fee cooling at night when the building is empty as the available free cooling is greater. This free cooling has to be stored in the building and this can be achieved if the building structure is also the ventilation duct. If hollow concrete chilled beams are used to duct the cool air throughout the building these beams absorb the cold and because of their thermal mass can release the cold by absorbing the building heat over the day when the ambient and building temperatures rise. These systems are becoming more popular and have been found to be most successful in balancing out cooling loads.

Other methods of night cooling are available including using vessels usually located underground filled with a high thermal mass material which is cooled during the night and the supply air passed through it during the day to supplement the existing cooling systems. Aquifers can also be used if water is available. ICE cooling can be carried out where ice is made by a refrigeration system at night when energy costs are low and allowed to melt during the day to absorb heat from the building.

Building location, colouring and shading can also be used to assist cooling. It has been the custom throughout the world that the buildings were coloured appropriately. In hot climates the buildings are normally white to reflect the heat. In cold countries the buildings are darker to absorb the heat. Modern building design now exploits the information about the location to produce the most suitable design taking into account location, weather conditions wind direction, sun aspect and shading. These now allow designers to specify the appropriate colour, window location, shading and materials to minimise energy consumption. Appropriate predictive control strategies can also be implemented.

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The most important advance in technology regarding building energy and low energy design is the introduction of truly intelligent building simulation and building control systems which are now able to predict the effect of occupancy and ambient conditions on the building and optimise the buildings response by switching of lighting, cooling and heating to unoccupied areas and optimise temperature control across the building using local sensors and actuators. These systems can predict high temperatures due to solar gains and take appropriate action before the building is over heated. They can optimise the use and interaction of the building H&V systems to minimise energy use and carbon emissions.

Free cooling and low energy systems are now available to allow every building to be operated efficiently and with minimum energy use and carbon emissions. There is now a will to implement these technologies. This will incur significant capital cost but will produce worthwhile economic and environmental benefits.

Acknowledgments

Building Services in the Greenhouse Spotlight, June 1998 issue of Building Services Journal by Dr David Fisk

Night Cooling Control Strategies, BSRIA March 1996 by Messrs Martin and Fletcher

Leaderer, BP and Cain WS (1983) Air quality in buildings during smoking and non smoking occupancy, ASHRAE Tran. 89 2A and 2B

BISRIA Free cooling systems (BG 8/2004)

Fig 5. Natural ventilation + Stack ventilation

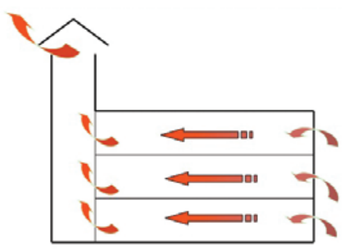


Fig 6. Natural ventilation + Wind scoop

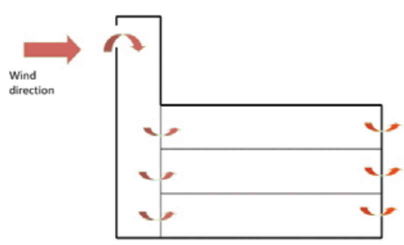
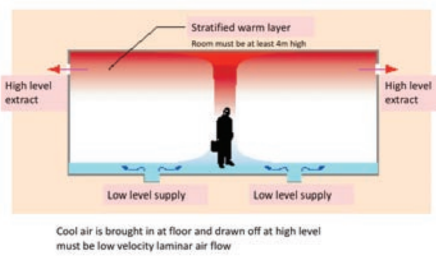


Fig 7. Displacement ventilation



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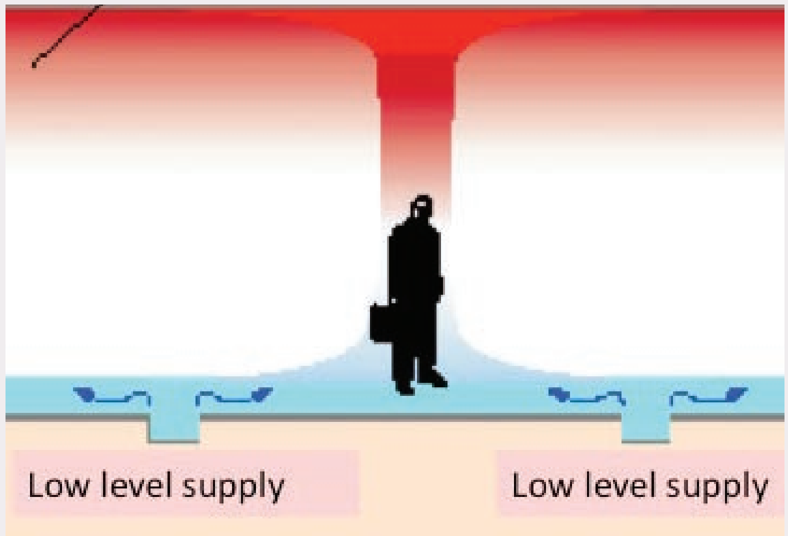

Questions

Please mark your answers on the sheet below by placing a cross in the box next to the correct answer. Only mark one box for each question. You may find it helpful to mark the answers in pencil first before filling in the final answers in ink. Once you have completed the answer sheet in ink, return it to the address below. Photocopies are acceptable.

1. What is free cooling?
- ☐ Free cooling is cooling which supplied free of charge
- ☐ Free Cooling is the use of naturally available cooling sources to provide cooling to building air conditioning systems.
- ☐ Free cooling is cooling which is supplied by refrigeration systems
- ☐ Free cooling is cooling which is carried out at night

2. What is now the minimum recommended air change requirement in public buildings in the UK?
- ☐ 8 air changes per hour.
- ☐ 24 air changes per hour
- ☐ 36 air changes per hour
- ☐ 20 air changes per hour

3. What is the average annual air temperature in all regions of the UK?
- ☐ 20°C
- ☐ 18°C
- ☐ Under 10°C
- ☐ 16°C

4. What is enthalpy?
- ☐ sensible heat + latent heat
- ☐ sensible heat - latent heat
- ☐ sensible heat x latent heat
- ☐ sensible heat / latent heat

5. What does adiabatic cooling mean?
- ☐ constant temperature cooling
- ☐ constant pressure cooling
- ☐ constant volume cooling
- ☐ constant enthalpy cooling

6. 100 per cent fresh air systems are normally fitted with:
- ☐ heat recovery or free cooling heat exchangers
- ☐ spray humidifiers
- ☐ reheat batteries
- ☐ chillers

7. Ground source heat recovery systems are normally buried how far underground?
- ☐ 5-6m
- ☐ 1-2m
- ☐ 2-3m
- ☐ 7-8m

8. Thermal wheels should not be used in what type of environment?
- ☐ dry
- ☐ cold
- ☐ wet
- ☐ contaminated

9. Passive ventilation systems will become standard in what?
- ☐ public buildings
- ☐ future buildings
- ☐ small buildings
- ☐ large buildings

10. Displacement ventilation is what?
- ☐ where the cold air is fed into the bottom of the rooms and exhausted at the top.
- ☐ cold air is extracted from the top of the room
- ☐ warm air is fed into the bottom of the room
- ☐ air is extracted from the bottom of the room